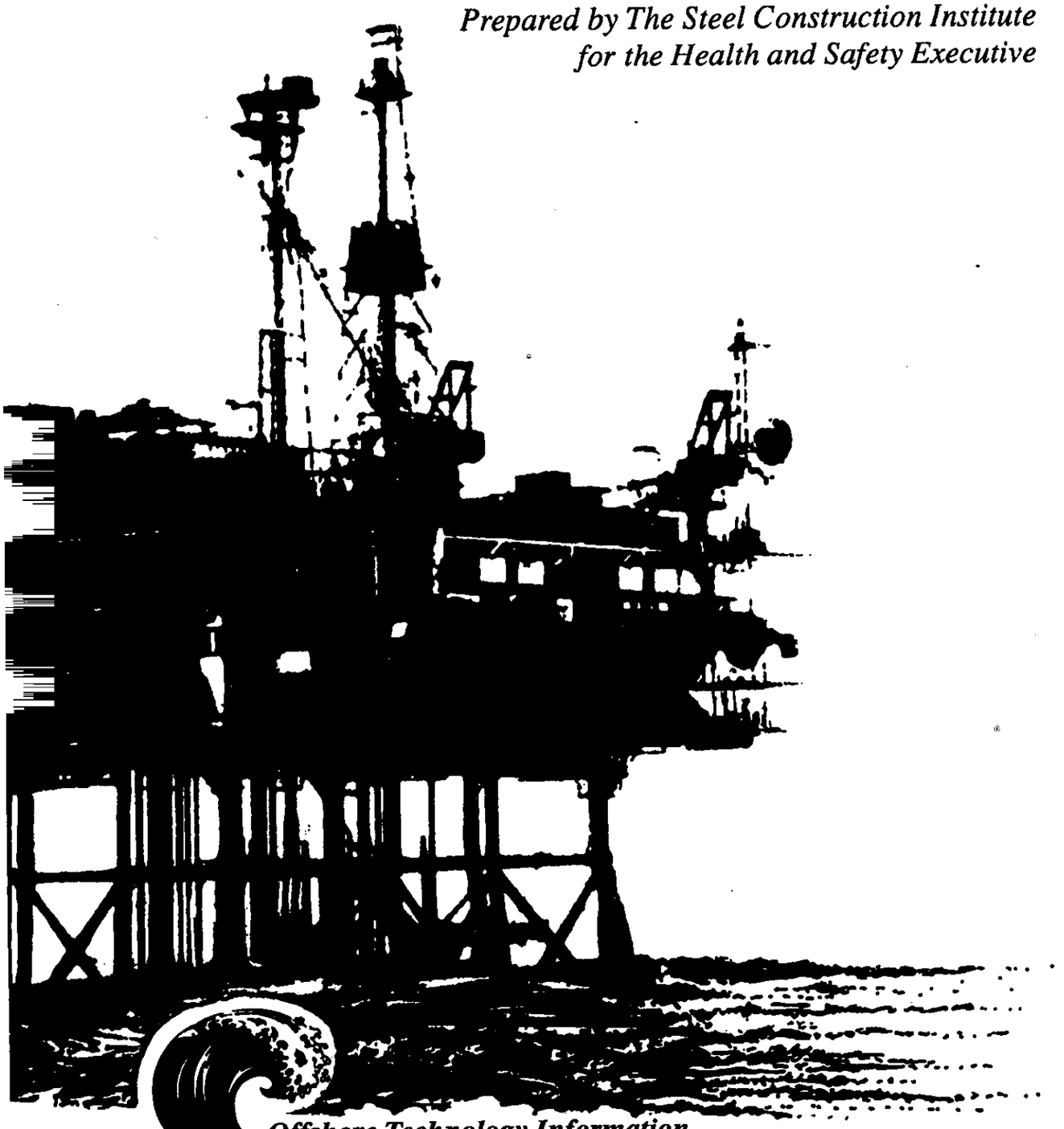
OTI 92 606

HSE
Health & Safety
Executive

PASSIVE FIRE PROTECTION: PERFORMANCE REQUIREMENTS AND TEST METHODS

Prepared by The Steel Construction Institute
for the Health and Safety Executive



Offshore Technology Information

Health and Safety Executive

OTI 92 606

PASSIVE FIRE PROTECTION: PERFORMANCE REQUIREMENTS AND TEST METHODS

This document was written by
Dr T Cotgreave of
Shell Research Limited
for
The Steel Construction Institute
Silwood Park
Ascot
Berkshire SL5 7QN

London: HMSO

Health and Safety Executive - Offshore Technology Information

© *Crown copyright 1992*
Applications for reproduction should be made to HMSO
First published 1992
ISBN 0 11 882095 8

This report is published by the Health and Safety Executive as part of a series of reports of work which has been supported by funds formerly provided by the Department of Energy and lately by the Executive. Neither the Executive, the Department nor the contractors concerned assume any liability for the reports nor do they necessarily reflect the views or policy of the Executive or the Department.

Publications in the Offshore Technology Information (OTI) series are intended to provide background information and data arising from offshore research projects funded by the Department, or the Executive, and major companies.

Results, including detailed evaluation and, where relevant, recommendations stemming from their research projects are published in the OTH series of reports.

HMSO

Standing order service

Placing a standing order with HMSO BOOKS enables a customer to receive other titles in this series automatically as published. This saves time, trouble and expense of placing individual orders and avoids the problem of knowing when to do so.

For details please write to HMSO BOOKS (PC 13A/1). Publications Centre, PO Box 276, London SW8 5DT quoting reference 12.01.025

The standing order service also enables customers to receive automatically as published all material of their choice which additionally saves extensive catalogue research. The scope and selectivity of the service has been extended by new techniques, and there are more than 3,500 classifications to choose from. A special leaflet describing the service in detail may be obtained on request.

FOREWORD

This report is one of twenty six work package reports written as part of the Joint Industry Project on Blast and Fire Engineering for Topside Structures. The Project Phase 1 started in May 1990 to collate, appraise and disseminate information on blast and fire loads, and on the resistance of structures and facilities to these loads. The titles and numbers of the reports generated by this project are as follows.

List of Reports

General

OTI 92 585 (G1(a))	Generic foundation data to be used in the assessment of blast and fire scenarios.
(G2 included in the above report)	Typical structural details for primary, secondary, and supporting structures/ components.
OTI 92 586 (G1(b))	Representative range of blast and fire scenarios.
OTI 92 587 (G1(c))	The prediction of single and two phase release rates.
OTI 92 588 (G3)	Legislation, codes of practice and certification requirements.
OTI 92 589 (G4)	Experimental facilities suitable for use in studies of fire and explosion hazards in offshore structures.
OTI 92 590 (G5)	The use of alternative materials in the design and construction of blast and fire resistant structures.

Blast Loading

OTI 92 591 (BL1)	Gas/Vapour build-up on offshore structures.
OTI 92 592 (BL2)	Confined vented explosions.
OTI 92 593 (BL3)	Explosions in highly congested volumes.
OTI 92 594 (BL4)	The prediction of the pressure loading on structures resulting from an explosion.
OTI 92 595 (BL5)	Possible ways of mitigating explosions on offshore structures.

Fire Loading

OTI 92 596 (FL1)	Oil and gas fires - characteristics and impact.
OTI 92 597 (FL2)	Behaviour of oil and gas fires in the presence of confinement and obstacles.
OTI 92 598 (FL3)	Current fire research, experimental, theoretical and predictive modelling resources.

Blast Resistance

OTI 92 599 (BR1)	The effects of simplification of the explosion pressure-time history.
OTI 92 600 (BR2)	Explicit analytical methods for deter mining structural response.
OTI 92 601 (BR3)	Computerised analysis tools for assessing the response of structures subjected to blast loading.
OTI 92 602 (BR4)	The effects of high strain rates on material properties.
OTI 92 603 (BR5)	Analysis of projectiles.

Fire Resistance

OTI 92 604 (FR1)	Experimental data relating to the performance of steel components at elevated temperatures.
OTI 92 605 (FR2)	Methodologies and available tools for the design/analysis of steel components at elevated temperatures.
OTI 92 606 (FR3)	Passive fire protection performance requirements and test methods.
OTI 92 607 (FR4)	Availability and properties of passive and active fire protection systems.
OTI 92 608 (FR5)	Existing fire design criteria for secondary, support and system steelwork.
OTI 92 609 (FR6)	Fire performance of explosion-damaged structural and containment steelwork.
OTI 92 610 (FR7)	Thermal response of vessels and pipework exposed to fire.

The purpose of these reports is to collate, review and critically appraise the current state of knowledge in each of the listed subject areas. They discuss the current state of technology as applicable to each of these areas. They also indicate the areas of significant residual uncertainty. The objectives and scope of each report are outlined in the 'Work Package Descriptions' included in each report.

The reports are written for use by engineers with specialist responsibilities for specific tasks associated with safety against potential fires and explosions in the design of Topsides on Offshore Structures (eg as part of a Formal safety Assessment) or for the use by their expert advisors. They are intended to be both expert and authoritative.

These reports have also been used as the basis for establishing interim guidance and to identify any necessary further research or development work. These are also project deliverables and are issued as separate documents.

This Project has been sponsored and funded by the following twenty nine organisations:

AEA Technology (Safety and Reliability Directorate)
Agip (UK) Limited
Amerada Hess Limited
Amoco (UK) Exploration Company
Arco British Limited
British Gas Plc
BP International Limited
Chevron (UK) Limited
Conoco (UK) Limited
Den Norske Stats Oljeselskap AS
The UK Department of Energy
Elf (UK) Plc
Enterprise Oil Plc
ESSO Exploration & Production (UK) Limited
Hamilton Brothers Oil & Gas Limited
Kerr-McGee Oil (UK) Plc
Marathon Oil (UK) Limited
Mobil North Sea Limited
Norsk Hydro AS
Occidental Petroleum (Caledonia) Limited
Petro-Canada Resources
Phillips Petroleum Co (UK) Limited
Ranger Oil (UK) Limited
Saga Petroleum AS
Shell UK Exploration and Production
Texaco Britain Limited
Total Oil Marine Plc
Ultramar Exploration Limited
Unocal (UK) Limited

CONTENTS

		Page
	EXECUTIVE SUMMARY	6
	GLOSSARY	7
	Organisations and Official Bodies	7
	Terms and Abbreviations	8
1.	INTRODUCTION	13
	1.1 Forenote	14
	1.2 Passive Fire Protection - Its Purpose	14
	1.3 Objectives of this report	14
	1.4 Background	14
	1.5 Scope and Methodology	16
2.	FIRE AND EXPLOSION EVENTS CONSIDERED	17
	2.1 Incident Scenarios	17
	2.2 Review of Events Considered	17
	2.3 Fire and Blast Loading Summary	21
3.	PASSIVE FIRE PROTECTION USAGE	22
	3.1 Generic Classification	22
	3.1.1 Preformed Sections	22
	3.1.2 Spray-Applied Materials	22
	3.1.3 Blanket / Wrap-Round Systems	22
	3.1.4 Prefabricated Sections	23
	3.1.5 Enclosures	23
	3.1.6 Seals and Sealants	23
	3.1.7 Water Fill	23
	3.2 Current Usage	24
	3.3 Pending and Possible Future Usage	24
	3.3.1 ESV's	24
	3.3.2 Pressure Vessels	24
	3.3.3 Risers	25
	3.3.4 Cable Trays	25
	3.3.5 Fire Mains	25
	3.3.6 Non-Ferrous Metal Substrates	26
	3.4 Usage Summary	26
4.	STANDARD FIRE TESTS FOR ELEMENTS OF CONSTRUCTION	27
	4.1 Fire Tests and Fire Curves	27
	4.2 Furnace Conditions and Assessment	28
	4.3 Summary of Standard Fire Tests	30

Page

5. PERFORMANCE CONSIDERATIONS 31

5.1 Installation Requirements 31
5.1.1 Surface Preparation 31
5.1.2 Retention System 32
5.1.3 Compatibility 32
5.1.4 Equipment and Operator Training 32
5.1.5 Health Hazard 33
5.1.6 Environmental Conditioning 33
5.1.7 Topcoating 34
5.1.8 Sealing 34
5.1.9 Weight Control and Coating Thickness 35
5.1.10 Quality Assurance and Quality Control 36
5.2 Pre-Fire Durability 37
5.2.1 Adhesion (Ability to Remain in Place) 38
5.2.2 Vibration Resistance 39
5.2.3 Resistance to Flexure of Substrate 39
5.2.4 Mechanical and Chemical Stability 39
5.2.5 Ageing 40
5.2.6 Weather Resistance 40
5.2.7 Abrasion and Erosion Resistance 42
5.2.8 Resistance to Hosing, Cleaning Agents and Process Fluids 42
5.2.9 Impact Resistance 43
5.2.10 Thermal Insulation 44
5.2.11 Low-Level Heat Resistance 44
5.2.12 Corrosion Aspects 45
5.3 Maintenance 45
5.3.1 Inspection 46
5.3.2 Recognition and Significance of Defects 46
5.3.3 Repair; Topcoat, Bulk, Substrate/Interface 47
5.3.4 Removal and Modifications 48
5.3.5 Hot Work Tolerance 48
5.4 Fire Performance 48
5.4.1 Protection; Stability, Integrity and Limited Temperature Rise 49
5.4.2 Influence of Test Material on Heat Input to Furnace 49
5.4.3 Resistance to Hose Stream / Deluge 50
5.4.4 Response to Thermal Shock 50
5.4.5 Geometric and Orientation Effects 50
5.4.6 Resistance to Jet Fires 51
5.4.7 Activation Temperature 54
5.4.8 Thermal Properties 54
5.4.9 Non-Combustible Materials 55
5.4.10 Smoke and Toxic Gas Production 55
5.4.11 Sudden Failure of Spent Material 56
5.4.12 Non-standard Fire Tests 57
5.5 Explosion Survivability 59
5.5.1 Physical State 59
5.5.2 Retained Protection Capability 60
5.6 Summary of Overall Performance 61

Contents

Page

6. CURRENT STATUS 62

7. AREAS OF UNCERTAINTY 64

8. REFERENCES 66

TABLES

Table 2.1 Fire Types
Table 3.1 PFP, Generic Types
Table 3.2 Current Applications of PFP
Table 4.1 Summary of Fire Ratings and Performance
Table 5.1 Accelerated Weathering Tests

FIGURES

Figure 4.1 Comparison of Fire Curves

APPENDIX A The FR3 Work Package

Contents

EXECUTIVE SUMMARY

This report appraises the performance requirements for offshore passive fire protective systems and assesses the adequacy of current tests for ensuring that performance. It considers the many aspects related to installation, durability under service conditions in the pre-fire phase, exposure to fire conditions likely to be experienced offshore, and the effects of explosions.

The objective of setting and assessing performance requirements for any system is to establish fitness for purpose.

The purpose of passive fire protective materials and systems is to delay or limit the effects of fire on structural and segregating elements or vital equipment. Therefore, to establish their fitness, it is necessary;

(a) to determine how the material or system performs when exposed to fire and
(b) to be able to predict that the material or system will be in position, in a suitable state, throughout its projected lifetime.

NEITHER IS FULLY SATISFIED BY CURRENT PRACTICE

Demonstration of an ability to meet certain performance criteria in standard fire tests is presently the primary measure of potential fire response. The fire tests are furnace-based and derive from onshore building practice. Meeting these criteria essentially fulfils the current requirements, for approval by regulatory authorities, for the use of passive fire protection offshore. However, the prescribed furnace conditions do not relate via thermal and/or aerodynamic effects to those of "real" fires. Other tests involving direct flame impingement may offer more of the characteristics of "real" fires.

Resistance to blast loadings depends upon the reaction of the substrate; response assessment remains in the experimental stage.

Smoke and toxic gas emissions from passive fire protective materials are currently considered in isolation and there is uncertainty about the overall life-threat significance of these emissions compared with those from the primary fire. Potential benefits may be lost by restricting the use of certain products.

Information on installing passive fire protection products is basically good but quality principles are not always followed during application. Likewise, once installed, maintenance is not always given sufficient attention to avert undue deterioration.

Where there is an absence of field experience for a given product, its long-term durability is uncertain. Only a very limited ability to predict future performance is provided by existing, accelerated weathering procedures. This inhibits the early introduction of new and improved systems.

Contents

GLOSSARY

Organisations and Official Bodies

API	American Petroleum Institute
ASFPCM	Association of Structural Fire Protection Contractors and Manufacturers Limited
ASTM	American Society for Testing and Materials
BRE	Building Research Establishment (UK)
BRL	Ballistics Research Laboratory (USA)
BSI	British Standards Institution: issuers of BS series of materials specifications, standard methods of testing, codes of practice and published document (PD) series, also ISO publications
CEC	Commission of the European Communities
DEn	Department of Energy (UK)
DnV	Det norske Veritas (Norway)
DOE	Department of the Environment (UK)
DOT	Department of Transportation (USA)
EEC	European Economic Community
FRS	Fire Research Station, a division of BRE.
HSE	Health and Safety Executive (UK)
IMCO	Inter-Governmental Maritime Consultative Organisation (see also IMO)
IMO	International Maritime Organisation (name changed from IMCO, May 1982)
ISO	International Organisation for Standardisation
NPD	Norwegian Petroleum Directorate
SINTEF NBL	Norwegian Fire Research Laboratory
SOLAS	The international convention for the Safety Of Life At Sea 1974, International Maritime Organisation, London (1974)
UL	Underwriters Laboratories Inc. USA

Contents

Terms and Abbreviations

Accommodation — Areas designated for living quarters, dining rooms, kitchen, pantries, recreation, offices, sick-bay, toilets and associated corridors, stairways and lifts.

Blast wall — A wall, purpose built and positioned to absorb or deflect the pressure waves and missiles generated from an explosion, to protect a vulnerable area.

BLEVE — Boiling Liquid Expanding Vapour Explosion; the result of a catastrophic rupture of a vessel containing a pressurised liquid at a temperature well above its normal boiling point. Associated hazards are missiles and simultaneous ignition of the vapourising fluid giving a short duration, intense fireball.

Blowdown — The controlled venting of a pressurised vessel or line on normal or emergency shut-down of a process.

Blowout (ignited) — A form of jet fire resulting from ignition of a high pressure flow of oil and gas issuing from an uncontrolled well, possibly with a substantial fall-out of heavy fractions which may also ignite on or around the platform as pool fires.

BS — British Standard, BSI document, these include specifications for materials, methods for testing and codes of practice.

Cellulosic (fire) — This term is used to describe a fuel source comprising solid materials formed predominantly from cellulose (e.g. timber, paper, cotton). A fire involving these materials is relatively slow growing compared to a hydrocarbon fire. See Work Package FL1 Section 7 for details. Protection against this type of fire has historically dominated the commercial/industrial fire scene.

Cementitious (pfp) — A cementitious pfp system is one that is based upon, or uses as a major component, a hydraulically setting cement such as ordinary Portland cement.

Cloud fire — A transient fire resulting from the ignition of a cloud of gas or vapour not subject to significant flame acceleration via the effects of confinement or turbulence. See Work Packages FL1 and FL2.

Contents

CO	Carbon monoxide: partially oxidised product of combustion of an organic compound (eg a hydrocarbon). CO has a marked narcotic effect due to its strong affinity for blood haemoglobin.
CO_2	Carbon dioxide: fully oxidised product of combustion of an organic compound (eg a hydrocarbon). CO_2 stimulates hyperventilation resulting in increased uptake of toxic gases.
Conduction	Heat transfer across a stationary fluid or a solid.
Control room	Area set up to house radio and navigation equipment, internal communications, central gas and fire detection and control, emergency power source.
Convection (convective heat transfer)	Heat transfer between a moving fluid and a surface.
Deck	A horizontal division within or upon a structure. It may be accorded a fire rating as for a wall or partition but for exposure to fire from below only.
Diffusivity	An expression relating to the quantity of heat (or mass) transmitted through a given medium to that absorbed by the medium. It has the units $m^2\ s^{-1}$.
ESV	An Emergency Shut-down Valve is intended to isolate a section of riser or export line. It is installed on a platform as near to sea level as practicable.
Fireball	A fireball is the rapid, turbulent combustion of fuel as an expanding, usually rising ball of flame. See Work Packages FL1 and FL2.
Fire curve	A temperature/time curve devised for a fire test that is intended to represent (but not necessarily reproduce) the temperature development of a "real" fire, either cellulosic or hydrocarbon.
Fire damper	A series of louvres or flaps installed in an HVAC duct designed to cut off the spread of smoke and fire through the ductwork.
Fire door	A door constructed and installed such that it does not impair the fire resistance of a wall. It should normally have a positive closing mechanism that can be operated from either side.

Contents

Fire resistance (rating)
: A quantified assessment of the time-dependent ability of a structure to resist prescribed combinations of (a) transmission of heat, (b) the passage of flame, smoke and toxic gases and (c) mechanical failure.

Fire test
: In the present context, a test designed to quantify the resistance to fire of elements of construction and/or materials applied thereto. Conventionally, such tests are carried out in purpose-built furnaces operating to a defined fire curve.

Fire wall
: A purpose built wall extending totally or substantially across a section of a platform and extending through one or more levels to segregate selected areas. A wall or partition, external or internal, having a rateable resistance to fire.

HCl
: Hydrogen chloride (gaseous form), hydrochloric acid (in aqueous solution): produced during the combustion of chlorine containing materials, e.g. polyvinyl chloride (PVC). HCl is a sensory and pulmonary irritant.

HCN
: Hydrogen cyanide (also known as hydrocyanic acid, prussic acid): produced during the combustion of nitrogen containing materials, e.g. polyurethane. HCN reacts with a enzyme rapidly inhibiting the body's utilization of oxygen.

Heat flux density
: Heat flux density is an expression quantifying the rate of heat transfer per unit area normal to the direction of heat flow. A convenient unit in the present context is kW m^{-2}.
(1 kW m^{-2} = 317 Btu ft^{-2} h^{-1}).

HVAC (ducting)
: Heating, Ventilation and Air Conditioning ducting: this presents a particular problem by providing a relatively easy passage through compartments for the products of fire (see fire damper).

Contents

Hydrocarbon (fire)
: A hydrocarbon is a molecule comprised exclusively of carbon and hydrogen. There is an enormous number of such species; the petroleum industry commonly deals with hydrocarbons ranging from one carbon atom (methane, natural gas) through to waxy and bituminous mixtures with several tens of carbon atoms. From the fire point of view, there is also a wide spectrum of other organic chemicals, solvents, treatment agents etc., with similar combustion characteristics producing a rapid temperature rise and sustained high heat flux density. See Work Package FL1 Section 7.

Intumescent (pfp)
: An intumescent pfp system is one based (generally) upon a polymeric resin that generates an expanded carbonaceous char on exposure to fire. Heat is absorbed from the fire in this process and the char has a low thermal conductivity.

Jet fire
: A turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular range of directions.

LPG
: Liquefied Petroleum Gas: the term applied to those hydrocarbons which are in the gaseseous state at normal temperature and pressure but which can be liquefied by compression and/or refrigeration. Propane (boiling point -42°C) and butane (boiling point -0.5°C) are the most common.

Mobil (fire test)
: A fire test protocol devised by Warren and Corona intended to emulate elements of a hydrocarbon fire.

NES
: Naval Engineering Standard: a standard issued by UK Ministry of Defence for contracts relating to vessels of the Royal Navy.

Overpressure
: The loading produced on a target subjected to the transient pressure pulse generated by an explosion.

Passive fire protection (pfp)
: A coating, cladding or free-standing system that provides thermal protection to the substrate or protected area in the event of fire and which requires no manual, mechanical, or other means of initiation, replenishment or sustainment.

Contents

PD — BSI Published Document

Penetration (seal)
: Pipes or cables, singly or in multiple arrays, penetrating a wall or deck, may impair the fire rating of the partition. Purpose-made seals, or seals formed in-situ to conform to more complex geometries, are available to redress the situation.

Pool fire
: For the purposes of this report, a pool fire is defined as a turbulent diffusion fire burning above an upward facing horizontal pool of vaporising fuel under conditions where the fuel vapour or gas has zero or very low initial momentum. See Work Package FL1 for details.

Primary structure
: All structural components, the failure of which would seriously endanger the safety of a significant part of the installation.

Radiation (radiative heat transfer)
: Energy (heat) transfer between two surfaces by emission and absorption of electromagnetic radiation.

"Real" fire
: All fires are real, but for the purposes of this report, "real" means any unplanned or accidental fire as distinct from a contrived, simulated or test fire environment.

Running liquid fire
: The burning of fuel vaporised from a mobile stream of liquid flowing across a surface (heated or otherwise). See Work Package FL1.

Section factor (H_p/A)
: A term used to express the ratio of fire-exposed perimeter to cross-sectional area of a structural element (beam, column, etc). It has the unit m^{-1}.

SI
: Statutory Instrument: UK regulation resulting from an Act of Parliament; in the present context, regulations governing offshore operations.

Thermal conductivity
: Heat transfer through a medium via random molecular motion. It has units $W\ m^{-1}\ K^{-1}$.

Toxicity index
: The result of a numerical summation of the concentrations of the components of a mixture of combustion gases in proportion to their individual toxicity ratings. The latter may be referred to either incapacitation or lethality.

Contents

1 INTRODUCTION

This document, FR3, is one of a series of documents relating to FIRE RESPONSE. It refers to reports in other series concerned with BLAST LOADING and with FIRE LOADING; the reports in the three series are listed below.

BLAST LOADING LIST:

- BL1 Gas/vapour build-up on offshore structures
- BL2 Confined vented explosions
- BL3 Explosions in highly congested volumes
- BL4 The prediction of pressure loading on structures resulting from an explosion
- BL5 Possible ways of mitigating explosions on offshore structures

---

FIRE LOADING LIST:

- FL1 Oil and gas fires - characteristics and impact.
- FL2 Behaviour of oil and gas fires in the presence of confinement and obstacles.
- FL3 Current fire research, experimental, theoretical and predictive modelling resources.

FIRE RESPONSE LIST:

- FR1 Experimental data relating to the performance of steel components at elevated temperatures (SCI).
- FR2 Methodologies and available tools for the design/analysis of steel components at elevated temperatures (SCI).
- FR3 **Passive fire protection - performance requirements and test methods (Shell Research Ltd).**
- FR4 Availability and properties of passive and active fire protection systems (SCI).
- FR5 Existing fire design criteria for secondary, support and system steelwork (SCI).

Contents

FR6 Fire performance of explosion-damaged structural and containment steelwork (SCI)

FR7 Thermal response of vessels and pipework exposed to fire (Shell Research Ltd)

1.1 Forenote

Throughout the period that the bulk of this document was being written, the Public Inquiry into the Piper Alpha disaster was being conducted by Lord Cullen. Just prior to completion, the results of the inquiry were published [1]. Relevant extracts or comment have been incorporated in or appended to appropriate Sections.

1.2 Passive Fire Protection - Its Purpose

The topsides of a platform comprise the upper sections of the jacket, support frames, modules, accommodation, process equipment, etc., and all are vulnerable, to a greater or lesser extent, to the effects of fire. A considerable measure of protection against fire can be gained by the use of passive fire protective coatings and systems, whose function is to limit heat transfer from the fire source to the structure. This delays the rise in temperature to critical levels, reduces the risk of escalation and buys time in which evacuation of personnel, blow-down of vessels, control and fire-fighting measures can be brought into operation.

1.3 Objectives of this report

To assess the performance requirements for offshore passive fire protective systems and the adequacy of current methods for the assessment or prediction of performance.

To identify gaps in the present knowledge, assess their implications and to suggest possible means of improving the situation.

The FR3 Work Package is reproduced for reference in Appendix A.

1.4 Background

The performance requirements for pfp are those directly related to the installation, endurance and operation of the materials and systems, to enable them to fuction effectively in order to provide the intended degree of protection.

Currently, the "official" requirements for the placement of passive fire protection are embodied in a number of

Contents

documents [2-9] stemming from the Safety of Life at Sea (SOLAS) convention (1974). The original publications were specifically aimed at shipping and have, to a large extent, "borrowed" from onshore experience and requirements for the protection of structural steelwork, and extended to the protection of bulkheads and deckheads. Areas are defined according to function and perceived risk and segregated by barriers having an appropriate degree of integrity, stability and fire resistance. In many cases, steelwork or other non-combustible material is deemed sufficient for the purpose, but where it is essential to limit the temperature of structural elements exposed to fire, then passive fire protective coatings have an important role.

For offshore platforms, the principal location for passive fire protective coatings is on the walls of control rooms and accommodation modules; the details may be found in the cited documents [2-9]. Throughout the offshore industry, the requirements noted in these documents are generally regarded as the minimum for safe operation and many operators specify more extensive protection and protection to a higher standard. Thus fire walls, process areas, structural members, pressure vessels, risers and ESV's may all be protected by passive coatings. Indeed, operators in offshore UK locations are currently being obliged to demonstrate a capability and to formulate urgent programmes for installing on-board ESV protection.

The acceptance and formal certification criteria applied to fire protection are principally centred on performance in a standard fire test and invariably, the performance of the virgin material only is assessed. Fire protection standards historically relate to exposure to a cellulosic fire and 1-hour protection (A60 rating) was the norm for wall-type structures. Various national and international standards exist and all use a temperature measurement as a criterion to quantify the fire resistance characteristics of the protected assembly. Typically, a mean temperature rise of not more than 140°C for the unexposed face of a bulkhead or a limiting temperature of 400°C for a column or beam is specified. The integrity, stability and retention of load-bearing capability, as appropriate, are also assessed.

It is widely recognised that hydrocarbon fires can be more intense than cellulosic fires and reach maximum heat flux density almost instantaneously, presenting a much greater thermal shock (see Work Packages FL1 and FL2). Emerging standards [10-12] based on protection against hydrocarbon fires typically require 2-hour protection, again based on temperature limits and the other criteria as noted above. For ESV enclosures, 100°C for 15 minutes and 300°C for 2 hours for the actuator and valve body, respectively, are examples of the limits that have been have been proposed.

Much attention is also being given to the special case of impingement by jet fires. No standards exist and the possible need for any is discussed later.

Contents

The other, major criterion for pfp is that it should be there and remain in place, in a suitable condition or in a labile state, ready to perform should a fire occur. In other words, what is needed is a robust, durable system whose properties do not deteriorate unduly with time in response to environment, use or abuse. Suitable mechanisms are required to ensure that systems are correctly installed and maintained and the extent to which durability aspects are considered in practice are discussed in detail.

Looking ahead, it is envisaged that the definition and development of a better test (or tests) incorporating fire parameters to complement or replace temperatures generated in a furnace will be pursued with the aim of facilitating predictions of performance in "real" fires. Similarly, means of predicting long-term behaviour will be sought via development of soundly-based, realistic, weathering programmes.

Fire performance and durability are the two main factors. Current knowledge in both areas is far from complete but there is sufficient background available in order to make a fair assessment of what is needed.

1.5 Scope and Methodology

This study aims to identify factors that are instrumental in providing, maintaining and evaluating passive protective systems with the ultimate goal of giving an assured level and duration of protection in the event of fire.

It is based upon literature searches and solicited information from informed sources, as listed in the report on Work Package FL3 of this programme, augmented with research experience.

A brief review of the principal types of passive fire protection and their applications is provided as a background to the study of performance requirements in relation to offshore fire scenarios. Fuller details of materials and systems are provided in Work Package FR4 and the primary fire and blast loading conditions in FL1 and BL4, respectively.

The performance aspects considered can be broadly grouped in relation to durability and resistance to explosion and fire. Test methods are appraised in similar vein and areas where further knowledge is required are highlighted.

Contents

2 FIRE AND EXPLOSION EVENTS CONSIDERED

2.1 Incident Scenarios

A fire can be broadly characterised by the type and physical state of the fuel involved and its source, the ventilation conditions, the intensity with which the fuel burns and its duration. Table 2.1 gives a brief outline of the types of fires of potential interest and their likely duration. Work Packages FL1 and FL2 provide a comprehensive review and appraisal of fire loading effects and behaviour of various fires.

An explosion may precede a fire or occur as a result of the involvement of a vessel that becomes a casualty of a fire. The rupture of a process vessel or the ignition of a gas or vapour could generate significant overpressures. Explosions are addressed in Work Packages BL2 and BL3; the resultant pressure loadings on structures are discussed in Work Package BL4.

2.2 Review of Events Considered

Fire events are considered with regard to their effect on pfp. The fire loading effects of particular relevance to the response and requirements for resistance of pfp are:

heat flux density and fluctuations

gas velocity and velocity/pressure fluctuations

long-term variations (growth or decay) and overall duration

The impact of a fire upon pfp derives from a combination of the above factors. The heat flux density is presented as the the short-term intensity of the fire. Fire severity is the intensity integrated over the longer-term duration. The thermal shock associated with rapid fluctuations in heat flux imposes additional thermal load.

The local gas velocity and rapid fluctuations in pressure create aerodynamic forces producing vibration and shear which may contribute to the destruction of the material. Susceptible assemblies may be penetrated by the hot gases or loosened, and certain materials may erode. Currently, assessment of the contribution of these factors is limited to strong, but largely unquantified, visual evidence.

High heat flux density and high gas velocities do not usually occur together, a high flux is more likely to be associated with low velocities and vice-versa.

Fire events are essentially described in relation to the fuel source and, where applicable, a qualitative indication of intensity and severity is given.

Contents

The principal fuel sources, cellulosic and hydrocarbon, can be quite readily segregated and the resultant fires differentiated on the basis of rate of growth from ignition. Throughout the petroleum industry, concern about hydrocarbon fires predominates since on an offshore platform, the typical inventories of hydrocarbon liquids and gases are the most prevalent sources of fuel.

Different classes of hydrocarbon fires are conventionally identified as:

cloud fire
fireball
pool fire
running liquid fire
jet fire
blowout

There is no corresponding sub-division of cellulosic fires.

Within these classifications, the magnitude of the individual fire properties may vary considerably, with extensive overlap between the various fire classes. The properties of a fully-developed cellulosic fire may also overlap with those of certain hydrocarbon fires. Furthermore, when fires occur in enclosed spaces or in the presence of obstacles, their properties may be modified and data relating to open fire situations may no longer be applicable. See Work Packages FL1 and FL2. A brief description of the various classes of fire and their likely impact on pfp follows:

Cloud fire

The hazards posed by the transient, low velocity flame of a cloud fire to any structural unit would not be significantly reduced by pfp. Any structure capable of physically supporting pfp would invariably have sufficient thermal mass to be not more than superficially affected, even when unprotected. Any effects of confinement or overpressure would be related more to structural response than to thermal response.

Fireball

A fireball is similarly of short duration, but generally of greater intensity and therefore has a greater potential for promoting ignition of nearby objects. However, the same argument against seeking the benefit of pfp generally holds true. In the case of a BLEVE, the probability of plant damage from missiles and escalation from newly created fire sources (jet, pool, etc.) should be considered, each in its own right.

Contents

Pool fire

A pool fire, either upon the platform or on the sea below, is an event of major importance which must be taken into account. The supply of fuel is essentially uncontrollable, although it may not be replenished, and it may burn for a considerable time. Depending primarily upon the composition of the fuel, and to a certain extent upon the ventilation conditions, a wide range of heat flux densities can be produced. The flames exhibit inherent pulsation and are affected significantly by wind, resulting in further purturbations in the heat flux. Gas velocities, at least in relatively small fires, are low. Pfp exposed to a pool fire could therefore experience considerable changes in heat load and thermally induced stress. It is not known how pfp wetted by the pool would react.

Running liquid fire

There has been virtually no work published on characterising running fires. The wide range of variables, surfaces, flow rates, fuel types etc., would make for a formidable task. The best guess that could currently be made is that the intensity and duration may be similar to those of a pool or some jet fires. Pfp in the vicinity of such a fire would be under comparable conditions. If the burning fuel flowed over a protected surface, the fate of the pfp would be impossible to predict.

Jet fire

It is impracticable to generalise on the characteristics of jet fires since the term covers a whole range of flames whose only common feature is that the fuel comes intially from a source with some initial momentum. The range of jet fire behaviour is described in Work Package FL1, Section 5.4 and 7, and the behaviour of jet fires in enclosures and around obstacles is discussed in Work Package FL2, Section 9.7. Jet fires can arise from relatively low pressure gaseous or two phase discharges and have characteristics (gas velocities and heat fluxes) overlapping those of pool fires.

Jet fires from high pressure gaseous discharges can have regions of high heat flux density and regions of relatively high velocity. In the jet fires studied, these extreme regions usually do not overlap. It appears, therefore, that pfp is unlikely to be subjected, simultaneously and over long periods, to very high aerodynamic forces and high heat fluxes.

Whilst the heat fluxes are called "high", values have recently been found to be rather lower than previously thought (see Work Package FL1, Section 7.4.3). Evidence is accumulating that the endurance controlling factor for certain materials, exposed to this limited subset of jet fires, arises from the aerodynamic forces. These tend to be highly specific for particular structures and orientations.

Contents

The duration of a jet fire is inventory-limited and isolation and/or blowdown can curtail the severity. Until this is accomplished, it may be necessary for the fire to continue to burn to avoid creating a further hazard by accumulating unburned fuel. Pfp on engulfed or adjacent structures has a potentially critical role in this situation.

Blowout

Blowout fires can be an extreme type of jet fire with mutiphase and multicomponent flows. There is essentially no information on their internal conditions but high heat fluxes and some erosive action might be anticipated. The response of pfp to such conditions can not be forecast with any degree of confidence.

Cellulosic fire

Cellulosic fires can not be discounted on an offshore platform. The potential for fires involving predominantly cellulosic materials (and synthetic materials with comparable combustion characteristics) is not insignificant. As examples, the contents of an accommodation area or a stack of wooden scaffold staging could present credible fuel sources. Whilst pfp installed to combat hydrocarbon fires will almost invariably be adequate to cope with a cellulosic fire, in areas where the risk of a hydrocarbon fire is demonstrably low, it may be advantageous to install pfp to a less onerous standard.

Short duration fires might activate intumescent systems causing the outermost regions to char. If any other fire developed soon after, the net effect would probably not differ much from that arising from a continuous exposure of similar total duration. On the other hand, a partially charred coating left exposed for some time might deteriorate from environmental effects. The residual protective capability may not be known; reinstatement to the original thickness may provide the only safe solution.

In considering the broad outline of likely fire events, the implication is that specifying pfp on the conventional basis of fire type, i.e. cellulosic or hydrocarbon, or even identifying a specific class of hydrocarbon fire, may not be particularly useful in terms of endorsing fitness for purpose.

Blast loading

With regard to blast loading, high overpressures could result in extensive plastic deformation of structural elements and unpredictable chances of survival for the associated pfp. Conditions imparting substrate deflections that remain within, or close to, the elastic limit are considered in this report regarding explosion survivability of pfp.

Contents

2.3 Fire and Blast Loading Summary

The fire load conditions of principal interest offshore, that pfp might be required to resist, are associated with hydrocarbon fires. The total impact of a fire is a combination of heat flux density and its fluctuations, local gas velocity, and pressure fluctuations. There is variation over a range for each of these key characteristics for fires of a given type, but there is also considerable overlap for fires that are otherwise different in form. A cellulosic fire tends to pose less onerous conditions than anything other than a transient hydrocarbon fire.

Protecting structures against short duration (transient) hydrocarbon fires with pfp is not necessary. Pfp may be the only option for protecting against fires where high gas velocities are present and a viable option for all other types.

Blast loadings producing deformations up to the elastic limit of the substrate are considered to present conditions against which tolerance might be reasonably expected.

Contents

3 PASSIVE FIRE PROTECTION USAGE

3.1 Generic Classification

Table 3.1 gives a broad outline of the generic types of pfp that may be used offshore and a brief description of each type follows.

3.1.1 Preformed sections

Preformed sections such as boards and panels may be made from glass, mineral or ceramic fibre with appropriate binding agents which may be organic polymers or inorganic cements. Epoxy resin based intumescent systems, ordinary Portland cement, and calcium silicate may be used alone, or in conjunction with fibres or low density fillers such as vermiculite, perlite, or fly ash. Boards and similar sections are often used as components of prefabricated sections since most of the inorganic and largely fibrous systems require extensive weather protection. Interior partitions and wall linings often incorporate preformed sections, excluding the intumescents. Intumescent materials and filled, synthetic rubber are examples of materials used to make preformed pipe shells.

3.1.2 Spray-applied materials

The paint systems used offshore are chosen on the basis of minimal flame spread and contribution to a fire, rather than those having a specific fire protective capability. On the other hand, a major portion of fire protective agents are spray-applied as high-build coatings and these include epoxy intumescents, high and low density cementitious coatings, mineral and ceramic fibre systems. These materials are usually used in conjunction with a weather protective topcoat as stand-alone systems, particularly outdoors. Wire mesh or expanded metal lath fixed to the substrate with welded steel pins is employed as a mechanical retention system. This holds the coating in place against the effects of explosion or temperature rise in a fire that would weaken the bonding via the primers, incorporating the interphase and interfaces, through to the substrate.

3.1.3 Blanket/wrap-round systems

These systems are usually based on glass, mineral or ceramic fibres as woven cloths and random fibre infills; sometimes with low-density fillers. Stainless steel stitching and protective meshes are also used. Blankets are usually impaled onto pins welded to the substrate and supported with chicken wire. Weather protection is essential; the greatest use is indoors, inside prefabricated sections and on under-deck areas. A synthetic rubber overwrap, incorporating cork granules as a low conductivity filler, is designed for use on risers.

Contents

3.1.4 Prefabricated sections

Prefabricated sections designed for exterior use comprise totally enclosed steel casements which are bolted or welded in place to form a fire wall. Fire-rated interior decks can also be formed by jointing purpose-made prefabricated sections. The components of door, shutter and window assemblies should be selected and co-ordinated not to impair the design fire rating of the wall into which they are incorporated.

3.1.5 Enclosures

Rigid enclosures such as those made for ESV's and their actuators are made from a variety of combinations of materials. Multi-layer, stainless steel foil assemblies, preformed calcium silicate boards, low density fillers and ceramic fibre form the main insulation media. The skin(s) of the box may be stainless steel or a fire resistant, glass reinforced, resin composite (GRP). Flexible enclosures are essentially tailored versions of multi-layer blankets or quilts, possibly with alternative heat resistive fillings.

3.1.6 Seals and sealants

Purpose-made seals are used to form a permanent barrier to the passage of fire and its products where penetrations or the conjunction of constructional units would otherwise facilitate ready access. They are also installed in a labile state whereby the seal is not effected until fire strikes, as exemplified by intumescent door seals. The form and mode of installation of such seals is governed by the intended use.

Sealants perform essentially the same function as preformed seals but are generally formed in-situ. They may comprise intumescent mastics that can be injected or moulded to seal gaps, or blocks of intumescent material that can be readily cut or drilled to accept pipes, cables, etc. Silicone elastomers are also used to seal joints where vibration and movement must be accommodated, for example where a conductor pipe passes through a deck.

Seals and sealants provide a back-up and/or continuity to primary fire protective media. They are not effective in isolation; their function and performance is strongly related to that of adjacent materials and components. They have an important role to fulfil, but they can only be assessed on their ability to sustain the fire performance of the surrounding elements or a complete assembly. Within the present terms of reference, they are not eligible for further, individual consideration.

3.1.7 Water-fill

Hollow sections can be filled with water which acts as a heat sink, ultimately absorbing latent heat of vaporisation on exposure

Contents

to fire. Anti-corrosion and anti-bacterial measures must be taken and a top-up system, balancing valves and venting are required for sustained operation. Such a system is not totally passive; furthermore, it is generally considered that water-filling adds too much weight for most topsides applications. Therefore water-fill is not considered further.

3.2 Current Usage

In Table 3.2, a broad description of various areas and construction elements on a platform is used to illustrate the diversity of usage of pfp, also to indicate where it is not currently used.

3.3 Pending and Possible Future Usage

3.3.1 ESV's

In the UK, a recent enactment (SI 1029) [13] requires that ESV's and their actuators "shall so far as reasonably practical be protected from damage arising from fire, explosion or impact". With regard to fire, this has been interpretated as a need to protect the actuator such that it is able to operate and close the valve in the early stages of a fire. The valve itself (and especially the primary sealing arrangement) should then be maintained at a condition wherein isolation capability is sustained throughout whatever extended period is deemed necessary to blowdown pipe-lines and vessels, control the fire, etc. A typical proposal for meeting these requirements is that the temperature of the actuator be kept below 100°C for a minimum of 15 minutes and that the temperature of the body of the valve should not exceed 300°C over 2 hours when exposed to a hydrocarbon fire. The protection system must be openable or demountable for access and maintenance for both valve and actuator, therefore the component parts must be provided with effective mating and sealing surfaces. The pipe spools to which the valve is fixed and the valve stem between the body and the actuator must be suitably protected also, so as not to form a ready path for heat transfer into the active units.

3.3.2 Pressure Vessels

It appears fundamentally correct that pressure vessels should be protected from fire to reduce the risk of rupture. The arguments against protecting pressure vessels, other than their support structures, are concerned with the effect that the thermal insulating properties of the protective system will have on the blowdown characteristics of the vessel in an emergency (which may not involve fire). The limitation of heat input from the surroundings may prolong the depressurisation process to an unacceptable extent. The balance of designed strength, service stresses, thermally induced stresses and the reduced strength of the steel of a fire-exposed vessel has to be taken into account.

Another argument against protecting pressure vessels is the consequent restriction of access for inspection. This could possibly be countered in some circumstances by consideration of the perceived anti-corrosion capability of certain coatings, together with the acceptance of internal, and selective external, inspections. See Work Package FR7 for more detailed discussion of pressure vessels and pipework.

3.3.3 Risers

The protection of risers has been under active consideration for some time, but not yet practiced. Cullen [1] (para. 19.16 and para. 19.15) advocates urgent investigation. For external risers, the prevailing conditions in and immediately above the splash zone dictate that any passive protection system must be inherently capable of resisting wave action and impact or be provided with a suitable outer defence system. In this respect, overwraps of heavy gauge synthetic rubber or metal sheathing have been proposed.

Hot risers also pose a problem, particularly for intumescent materials. At or above about 100°C, decomposition reactions may start, albeit slowly, but nevertheless this is an undesirable state. A proposed solution is to provide an inert insulation layer, for example ceramic fibre, next to the steel and to overcoat this with the intumescent either as a spray-on system or as preformed shells.

3.3.4 Cables and Cable Trays

Electric cables carrying power and signals to vital equipment, emergency lighting and communications need to withstand the effects of fire for extended periods. Furthermore, it has long been recognised that electric cables may provide a ready path along which a fire could propagate from one zone to another. Accordingly, cables are produced which are designed as "fire survival" and "reduced propagation" types to counter the respective problems. Much attention has been devoted to the formulation of the insulation, bedding and outer sheath materials to provide the necessary fire resistance coupled with reduced emissions of smoke, toxic and acid gases. There are also various overwrap, spray-on and enclosure systems available to protect installed cables and their supporting trays, together with proprietary penetration seals for decks and bulkheads.

3.3.5 Fire Mains

The protection of fire mains has generally not been a requirement. Replication using different routes has been preferred. Alternative materials for constructing fire mains have been considered; in particular GRP provided with a fire protective layer is an option. Apart from elimination of corrosion problems, the ability to be exposed to fire in a "dry" condition and then to receive water immediately is an advantage over steel pipe.

Contents

3.3.6 Non-Ferrous Metal Substrates

The protection of steelwork is by far the greatest field of application of pfp. However, the weight-saving advantages of using aluminium for certain topsides construction may be better realised if the benefits of using pfp could be fully exploited. Blake [14] considers that an aluminium structure, protected with an appropriate thickness of epoxy intumescent to accommodate the temperature limitations of aluminium, could offer a viable weight-saving alternative to steel. See also the report on Work Package G5.

3.4 Usage Summary

There is a wide range of pfp materials and systems. The larger portion, in terms of volume used, are designed to isolate and protect designated areas and vital structures. Specialist variants of pfp are designed for specific applications.

Contents

4 STANDARD FIRE TESTS FOR ELEMENTS OF CONSTRUCTION

4.1 Fire Tests and Fire Curves

Various national fire tests exist which are based on cellulosic fires. They are all essentially equivalent and several are harmonised via international standards (see, for example, PD 6496 which compares BS, ISO and EEC equivalents [15]. The relative severities of the ISO 834 and ASTM E119 tests are compared by Harmathy [16]. The form of the cellulosic fire curve universally adopted is typified by that defined in BS 476 Part 20:

$$T = 345*\log_{10}(8t+1)+20$$

Where T = furnace temperature (°C)
t = time from ignition of furnace (min)

The initial furnace temperature is required to be within the limits of 5 - 35°C.

There are also furnace-based hydrocarbon fire tests and a corresponding algorithm for the hydrocarbon fire curve is given in Appendix D to BS 476 Part 20 (issued April 1990), quoted from ISO 834 and adopted by DEn/NPD as an interim standard:

$$T = 1100*[1-0.325\ \exp(-0.1667t) - 0.204\ \exp(-1.417t) - 0.471\ \exp(-15.883t)]$$

A graphic comparison of the resultant fire curves is given in Figure 4.1.

Under either heating regime, the elements of construction considered in BS 476 are:

Part 21 Loadbearing elements (beams and columns, partitions - walls, floors and flat roofs - fire from below only).

Part 22 Non-loadbearing elements (partitions, door sets and shutter assemblies, ceiling membranes, glazed elements).

Part 23 Components (suspended ceilings, intumescent seals for doors).

Part 24 Ventilation ducts.

Contents

Assessment criteria prescribed for partitions are:

Stability - the structure, loadbearing or otherwise, should not collapse within the test period of 120, 60 or 30 minutes in order to achieve an "H", "A", or "B" rating, respectively.

Integrity - the structure should not permit the passage of flame, smoke or toxic gases for the same periods of time noted above.

Insulation performance - the rise in temperature measured at points on the unexposed face of the structure should not exceed defined limits within set times. For "H" and "A" ratings, these are: mean temperature not more than 140°C above original and temperature at any point not more than 180°C above original.

For "B" ratings, the mean temperature rise must not exceed 140°C and the temperature rise at any point must not be more than 225°C above original.

The fire rating of a partition is determined by the ability to fulfil these conditions for set periods of time as summarised in Table 4.1 In all cases, where stability and integrity are specified, this equates to the full duration of the test.

The assessment criteria for beams and columns whether simply supported or constrained are;

Stability - a beam must not deflect beyond a set limit related to its depth and span and a column must not buckle.

Loadbearing capability - elements must continue to support a test load without collapse.

Insulation performance - the temperature of the protected element should not exceed 400°C or other such temperature as agreed with an approving authority.

4.2 Furnace Conditions and Assessment

Whilst standard fire tests are designed to represent a particular type of fire they do not purport to reproduce actual or "real" fire conditions. A standard fire test simply provides a reproducible time/temperature heating regime and environment within which the response of test specimens can be assessed against various criteria. It provides conditions in the furnace cavity that may approximate to some arbitrary position in a fire zone not directly affected by flame impingement. The furnace temperature and total heat flux may be similar to those generated within a fire but the wider range of fire variables, such as the

Contents

balance of radiative and convective heating, pressure fluctuations due to turbulence, high gas velocities, thermal shock and differential heating are not specifically included or controlled. Certain factors, i.e. high gas velocities, fluctuating pressures and heat fluxes, may be particularly critical with regard to the response and performance of pfp in a "real" fire.

It is recognised that total heat flux density is of more fundamental importance than temperature in defining thermal load and there have been various moves to use heat flux sensors to monitor and control furnace conditions. So far these have failed to provide reproducible control due to the inability of currently available hardware to tolerate sooting and contamination in the furnace environment (see Section 5.4.12).

It must be appreciated that a "cellulosic" fire test or a "hydrocarbon" fire test refers only to a test carried out in a furnace operating under the temperature conditions defined by the relevant fire curve (see Section 4.1).

An assessment of fire performance or resistance in a standard fire test is in effect a determination of an inspection property, i.e. it has essentially no validity outside the defined test environment. A "1-hour" or "2-hour" rating means simply that acceptable responses have been sustained for these periods in the relevant tests. It does not mean that comparable performance would be achieved in a "real" fire nor does it necessarily provide a means of predicting what performance would be achieved in any fire event, although quantified results could be used in validation of a suitable model.

Within the above constraints, monitoring temperatures on partitions, columns and beams provides a particularly relevant and direct means for assessing the performance of pfp on these substrates. The stability, integrity and load-bearing aspects generally relate to the effect of heat on the construction element itself and are thus of secondary interest within the immediate context, even though the heat has been accumulated by transmission through the pfp. In principle, the temperature dependance of stability and load-bearing capacity of the structural element could be derived by other means.

Other aspects of fire performance relating to pfp are discussed in Section 5.4.

Contents

4.3 Summary of Standard Fire Tests

Existing, standard, fire resistance tests are carried out in a furnace environment which is programmed to represent (but not reproduce) a cellulosic or a hydrocarbon fire.

The furnace programmes are based on temperature rather than heat flux density and the thermal shock of short-term variations in flux can not be incorporated. There is no provision for creating the aerodynamic effects of high gas velocities and short-term fluctuations in pressure. These are major factors whose potential importance in "real" fires has been identified. Assessment of fire performance of pfp via standard fire tests centres primarily upon demonstrating an ability to meet set temperature criteria on the protected element.

Contents

5 PERFORMANCE CONSIDERATIONS

5.1 Installation Requirements

For a fully compatible and properly engineered system to be installed, attention to detail that ensures adequate quality and, at the same time, achieves a level of practicality commensurate with offshore construction and operations, is required. A number of documents indicate this in general terms [17-21] and others deal with specific aspects, albeit in scant detail.

5.1.1 Surface Preparation

A basic requirement for a material that is wet applied to a substrate is that the substrate should be clean, dry, and stable, i.e. not bearing flaking rust or old paint, etc. The manufacturers of most proprietary products make this quite clear in their literature. Blast cleaning to a recognised standard (usually SA 2½), application of an anticorrosion primer, sealcoat and tackcoat may be included in the manufacturers' recommendations; these are frequently specific to particular products. A critical appraisal of the need to prime steel for cementitious products, other than magnesium oxychloride, for "normal" use is given by Latham [22]. The general principles of surface preparation for accepting cementitious coatings are given in a British Standard [23] and a corresponding Draft Standard [24] has been prepared for intumescent coatings.

The need for surface preparation to a standard that is acceptable to the product is indicated by Dunk [25] who quotes minimum cleaning standards and gives examples of tolerable primer thickness and bond strengths for a proprietary intumescent product.

The need for a sound anti-corrosion coat for use with magnesium oxychloride is advocated by Stewart [26]. This is a key defensive argument in the considerable controversy about the corrosion promoting potential of this medium.

In general, surface preparation is of the form and to standards that are widely used to serve anti-corrosion and painting requirements and quality is assessed using techniques well established in the paint industry (see Section 5.1.10). Once completed, however, the interphases created are "buried" for life beneath the fire protective medium and any deterioration, prior to catastrophic failure, can be assessed reliably only via removal of the overlying material.

For systems that are applied as preformed boards or panels, the common sense precaution of removing loose material and excessive rust is usually stated. Preformed claddings need less surface preparation but joints need special attention [27] to avoid penetration by (a) the environment and (b) fire.

Contents

5.1.2 Retention System

The mechanical retention system [23], used to retain the bulk product, to stabilise the char if appropriate, or to enhance resistance to blast and deformation of the substrate, may comprise one or more of the following:

expanded metal lath
ribbed metal lath
welded rectangular mesh
woven hexagonal mesh (chicken wire)

Depending on the type of substrate and its geometry, the retention system may be fixed onto welded studs, clipped in place, shaped or simply wrapped around and held with tie wires. The recommendations made relate to the intended function of the mesh and are directed to the dimensions of mesh that will allow efficient penetration by the coating (spray) and avoid setting up a plane of weakness.

Consideration of additional support or reinforcement, particularly where the construction does not allow encapsulation, or where there is no re-entrant detail, is suggested by the widely quoted ASFPCM source [28].

Where studs or pins are used, these may be welded in place after the main surface preparation (Section 5.1.2) has taken place, therefore local treatment may be necessary to restore the continuity of the anti-corrosion barrier; Section 5.2.12 considers corrosion aspects in further detail.

5.1.3 Compatibility

Passive fire protection rarely comprises a single component. A fire protected structure should be considered as an integrated system from substrate via primer, retention system, fire protective agent and topcoat, etc. Each of the components in a given system must be either intrinsically compatible with the others [25,29], inert [30], or suitable barriers or interfaces must be provided. As an example, it is maintained that chloride containing hydrated salts can be used to protect steel, despite their potential corrosive action under certain circumstances, provided that an effective anti-corrosion interface is used. It is also possible that it is required to protect adjacent parts of a structure with different fire protective materials [27], in which case there exists an obvious, minimum requirement that there should be no adverse interaction between the two systems.

5.1.4 Equipment and Operator Training

The sophistication of equipment and operator skills necessary to apply passive fire protection range from simple hand tools [29] to dedicated spray equipment [31], and from minimal training [32] through to manufacturer-certified specialist applicator

Contents

status [33]. There are no grounds for suggesting that increased sophistication of the method/applicator combination is the sole factor in achieving sound performance, although obviously it must be adequately matched to a particular product. However, practical observations suggest that the achievement of optimum performance from a given product is more strongly linked to the diligence with which the manufacturer's instructions and procedures are followed.

5.1.5 Health Hazard

It is a desirable feature that a fire protective coating system should not present a health hazard to workers during installation or thereafter [32]. Safe installation, at least during installation on modules onshore, is subject to observance of regulations such as COSHH [34]. This excludes considerations of toxic products produced during exposure to fire, which will be dealt with separately (Section 5.4.10). It has been specifically noted [32] that a product should contain no asbestos or banned particulates. Statements advocating non-flammability [32] discriminate against the use of organic polymer based intumescents, and whilst this may represent an ideal, acceptance of some limited fire risk, with due attention to precautions, is generally considered a practical alternative to enable other benefits to be realised.

5.1.6 Environmental Conditioning

Environmental conditioning is generally not considered a problem for assembly of preformed boards, sections or other dry-applied materials [30]. However, the following considerations could apply to the use of adhesives, sealants and caulks used in such construction. These materials are usually organic based polymers which are caused to undergo chemical change in-situ passing through various stages of gellation and cure. The same applies to polymer coatings (intumescents) which also undergo some post-cure (cross-linking) reactions to form a more rigid, 3-dimensional network.

The application site must therefore be regarded as a reaction vessel which has to provide the right conditions for the desired chemical reactions to proceed at an appropriate rate. In practice this usually translates into achieving an acceptable temperature of both the substrate and the surrounding air and not exceeding a set level of humidity, beyond which unwanted reactions could occur. The conditions must be held for a defined time to enable the reactions to go to completion. This is also important for any post-cure phase. Overall this may be seen as a (short term) disadvantage in that fair weather [27] or local environmental control is required before installation can be contemplated. On the other hand, the enhanced certainty of producing the desired product once the correct conditions have been achieved must be weighed against possible uncertainties associated with systems claimed to tolerate more lax environmental control. Publication of test and performance data from materials produced at the

Contents

prescribed environmental limits would add to confidence for their selection and use.

Some characteristic data have been published by Dunk [25] for an epoxy intumescent system.

> Steel temperature to be not less than 3°C above the ambient dew point and rising
>
> Preferred substrate temperature 10°C+
>
> Gel time @ 10°C, 10.5 hours
>
> Full cure @ 10°C, 36 hours

Cementitious products (and mixed salt hydrate cements [29]) are usually regarded as requiring no special environmental conditions for application. However, extremes must be avoided; surfaces must be free from excess water and drying should not be done too rapidly in order to avoid cracking; several weeks may be required to reach a stable water content. Water repellant agents may be incorporated into cement-based systems. These may require their own drying regime to ensure correct activation; as with most proprietary systems, the manufacturers make specific recommendations.

5.1.7 Topcoating

The need for topcoating ranges from essential, to exclude ingress of water as liquid [35], through desirable, for aesthetic reasons, to no requirement, except for conditions of intense, incident, ultra-violet light [25]. The type of system, cementitious or intumescent, and the constitution and properties of the individual product largely determine whether a topcoat is used or not, and if so, what sort. Usually, for exposure in a maritime environment, the safer approach of specifying a topcoat is adopted. In such case, it is essential that it is installed to an adequate specification and properly maintained.

5.1.8 Sealing

The bond between the fire protective medium and the substrate can generally be taken to be mechanically sound but boundaries or discontinuities, such as the edges of plates, can produce high stress intensities which can lead to local disbonding. For certain systems, it is often advised that additional treatment is given to this area to prevent ingress of water. Likewise it is common practice to construct water-shedding detail where fire protective coatings terminate on exposed members. Mastics and/or shaped metal flanges may be used. Formal requirements for sealing do not appear to exist; good site practice is relied upon instead.

Contents

5.1.9 Weight Control and Coating Thickness

Weight control is primarily concerned with topsides loading and coating thickness relates to an assurance that a given degree of fire protection has been installed. The two are inevitably linked, in that for a given system, a certain thickness per unit area will produce a total load that must be allowed for in design calculations. Furthermore, especially in the case of water absorbing species, a margin must be allowed for weight gain, particularly in exposed locations. In a more critical [11] or retro-fit situation, the existance of a maximum permissible load may preclude the use of certain products, as too may the inability to accept local strengthening [27]. On the other hand, should pfp be used in the splash zone, it may be possible to take advantage of some corrosion protection capability and effect a trade-off by reducing local thickening of structural steel.

In determining the thickness of coating to be applied to structural members, recourse is often made to tables of thicknesses determined from data accumulated from past fire tests such as those compiled in the ASFPCM book [28]. However, the current (2nd) edition comments that laterally restrained beams loaded to the requirements of BS 5950 Part 1 [36] are subjected to some increase in stress levels over beams loaded in accordance with the earlier BS 449. Whereas the vast majority of fire resistance tests have been carried out under loading conditions to BS 449, the precise situation with regard to revising the thickness of coatings to accommodate increased stress at the "fire limit state" is yet to be resolved. In the case of columns or struts (under compressive load) and depending on the type of section, either no increase or a step increase of 10% in thickness is recommended. The concept of Section Factor, H_p/A, for structural elements and methods of calculating this factor for various sections, degrees of shielding, profile and box sections are described together with rules for interpolating thickness and limits of applicability. A safety factor on thickness due to rounding up and converting test panel data to minimum thicknesses on site is defined.

Tolerance limits for relative areas of reduced thickness are given; these are slightly more conservative than those in a CEC report [22]. Thin areas of coating can be compensated for to a certain extent by increased thicknesses applied in surrounding or immediately adjacent areas. The need to consider global minimum thickness constraints for spray applied materials is highlighted. The actual thickness of coating decided upon must be practical to install [37]. Precautions relating to stacking sequence for laminating two or more layers of preformed boards of different thickness are also signalled.

Finally, it must be pointed out that unless expressly stated otherwise, such tables refer to performance in a furnace operating to a cellulosic fire curve. They do not necessarily relate to performance in an actual fire of whatever origin and no fully

Contents

validated, fundamental "conversion factors" exist in the open literature for translation to a thickness giving equivalent performance in a furnace operating to a hydrocarbon fire curve. Nevertheless, manufacturers do use empirical relationships to assist in determining the thickness of a given product required to meet the criteria of the hydrocarbon fire test.

5.1.10 Quality Assurance and Quality Control

Of the documents reviewed, only one [27] hinted at quality matters. Whilst checks may be made at various stages of installation, there appear to be some variations in what is practiced on site. In at least some instances, there is a distinct lack of sampling and recording of passive fire protection materials and components, and documentary evidence of the installation issued to the user. This, in part, must be due to operators not insisting that such evidence be produced and the hitherto lowly status of passive fire protection.

At the surface preparation stage (Section 5.1.1), quality control of cleaning and/or grit blasting is based upon visual observation and comparison with photographic standards. This may be supplemented with measurement of the surface profile generated by the grit blast on representative test plates. The film thickness of paints and paint-type coatings or interlayers may be assessed by direct measurement, ultrasonic, inductance or capacitance techniques or inferred from weight checks.

The quality of a retention system (Section 5.1.2) is dependent upon having correctly placed and firmly fixed pins or studs and/or firmly attached or bound mesh, etc. Apart from overall visual observation, individual pins or sections of mesh can be destructively tested, but it would be difficult to assign other than qualitative value to the results.

On-site quality control of the bulk pfp medium may require attention to storage conditions, e.g. temperature, humidity, shelf-life. Prior to use, visual checks may be made for phase separation, colour, chemical reactivity, density and flow characteristics, as pertinent to the material in question. During application, particularly of spray-applied systems, it may be necessary to control delivery rates, ratios of multi-component systems and thickness of individual layers. This may be achieved by timing and weighing pump deliveries and trial applications. Provision and scope for permitted corrective action and authority for approval should also be included.

Individual and total layer thickness may also be assessed directly by use of probes or non-destructively via capacitance or ultrasonic measurements. The latter can also detect debonded areas. However, none of these methods can guarantee that the design thickness has been applied overall without extensive measurements being made. For each installation, a matrix of measurement sites, which would allow detection of significant

Contents

areas that were out of specification (see, for example, Section 5.1.9), should be prepared.

Final surface finish and topcoating and sealing are again largely subjective and a mixture of manufacturers' and users' guidelines for good practice and common sense prevail. It is generally implied that a good, continuous surface, free from defects and an essentially smooth finish is achieved.

Day [38] has directed attention specifically towards thin film systems for buildings but more general questions are raised. Whilst there is no formal requirement, the opinion is given that quality control, installation contractors, identification of passive fire protective coatings, material specification checks, quality assurance to BS 5750 [39] and the effect of physical factors that may affect performance should all be included in a quality package.

A further principle of good quality assurance could be instituted by operators engaging independant agents to inspect the product throughout application and to monitor the quality control of the manufacturer and applicator.

5.2 Pre-Fire Durability

Passive fire protection can be regarded as a line of defence; in a totally secure situation it will never be called upon to perform its intended function. Practically, once installed, a pfp system will probably spend much or all of its life in an inert, compliant or labile state, depending on the type of system, ideally without losing any of its potency. However, throughout this period it will inevitably undergo natural ageing to whatever extent, and have to endure various aspects of use and abuse.

Given that this phase is likely to represent a major portion of the system's life, it is surprising that, with a few exceptions, apparently little attention has been directed to defining and evaluating requirements. ASFPCM [28] refers to BS 8202 [23,24] for aspects other than fire resistance and, in the case of intumescents, states "the specifier should satisfy himself regarding manufacturers' claims associated with durability". Petrie and Knight [27] simply note that systems "should possess satisfactory durability to the hostile marine environment", (which for the present purposes should be more correctly interpreted as " - - maritime environment", except specifically in the case of the splash zone).

Whilst the overall durability package can be broken down into a number of specific aspects, the definition and quantification of actual requirements is quite difficult. Some features are obviously specific to a particular type of pfp or product and may thus be easier to define and measure; others can only be described

Contents

in the broadest terms This is particularly the case where the external agent or force that the material is called upon to resist is ill-defined.

5.2.1 Adhesion (Ability to Remain in Place)

It is a fundamental requirement of passive fire protection, whether sprayed in place or mechanically fixed, preformed sections, that it should remain firmly in place so that it can perform its intended task. In most cases, a bond is formed through to a steel substrate via one or more layers comprising an anticorrosion system. Although both cohesive and adhesive mechanisms operate through and between each layer, respectively, it is convenient to think of the whole as adhesive in relation to the bulk coating. As an aside, spray-on systems which are built up to total thickness in a number of discrete passes may also incorporate interfacial regions where adhesion becomes important.

It is clearly a deficiency of the system if the adhesive strength is significantly less than the cohesive strength of the bulk material, unless the design includes comprehensive mechanical fixing or encapsulation. Adhesive strength must be maintained throughout the range of temperatures experienced in normal service [41]. On exposure to high temperatures [22], however, failure of adhesive bonds can be expected and cohesion and mechanical retention will then predominate.

Latham [22] quotes an adhesion test, ASTM E-736 (1980), which uses a spring balance to exert a tensile force with an arbitrary maximum load of 12kg (≡ 500 kPa), but notes that this bears no relationship to the total range of insulant strengths found in practice. Similar minimum limit values are quoted by Wesson [31] and Van Dyke [32] and, indeed, these relate principally to cementitious products with strengths which may approach the order of 1 MPa. By comparison, the bond strength exhibited by an epoxy intumescent [25] is of the order of 6 MPa.

For cementitious products, it has been stated [32] that they should make surface-to-surface contact with the substrate with no space or air gaps. This is clearly not applicable to the use of preformed sections of either cement based or organic intumescent products which have bolt-through or banded fixings.

As a general requirement, therefore, whether or not adhesion to the substrate is a critical mechanical factor, a given system should exhibit a level of adhesion that ideally will resist all applied forces up to those which cause destruction of the bulk material. This then includes the situation, for example, where the adhesion of a coating serves to exclude ingress of corrosive agents, in which case it may be necessary to boost the adhesion by use of a tack coat.

Contents

5.2.2 Vibration Resistance

A characteristic feature of offshore structures is the continuous presence of low frequency vibration. That passive fire protective coatings should be able to cope with this without becoming detached from the substrate is noted by Blake [17] and others [37] and there is a parallel comment from the field of rail transport by Levine [19]. The latter suggests vibration testing at the resonant frequency of the structure (but for an unspecified period and presumably followed by a bond strength determination).

Resistance to vibration is manifest as resistance to crack propagation and fatigue in the bulk material and/or adhesive interfaces in coating materials and does not necessarily relate to absolute strength values.

Similar considerations apply to the elements of mechanical retention or encapsulation systems. An assessment of susceptibility to crack propagation and the nature of failure can be gained via fracture toughness measurements on notched test specimens. Cumulative damage under fatigue conditions can be predicted from crack propagation measurements made during cyclic loading of similar specimens (Miner's law). Using this information, prediction of time to failure of a particular element is theoretically possible, but only provided that the local amplitude, frequency, duration and mode of vibration can be adequately described.

5.2.3 Resistance to Flexure of Substrate

Virtually all surfaces to which passive fire protective coatings are applied are liable to experience some degree of elastic flexure in the normal course of events. One particularly testing time is load-out of prefabricated modules. This is noted in general terms [26,37] and specific comment that bonding can be sustained beyond the plastic limit of steel is given by Dunk [25]. A further event to be considered is the rapid response to flexure and deformation as a result of an explosion (see Section 5.5).

Conventional mechanical testing can indicate the ability of a coating to resist simple flexure to any given extent. When bonded to a substrate, a more complex situation exists, particularly at discontinuities, which requires consideration of the geometry and resultant stress concentrations.

5.2.4 Mechanical and Chemical Stability

That the materials and systems should be stable and not crumble and disintegrate or change to chemically different species is an obvious requirement. However, acknowledgement of these points and means of verifying stability are far from comprehensive.

Herrera [29] comments on mechanical stability from the point of view of shrinkage and cracking (of cements). Following

Contents

accelerated weathering stability checks on an intumescent material, O'Rourke [42] used visual examinations to check for efflorescence, chalking, blistering, flaking, erosion and leaching. Chemical analyses confirmed that the elemental composition had not changed significantly but subsequent simple fire tests were inconclusive. On a different product, Castle [41] conducted intumescence tests after solvent immersion and found no change.

The dominant mechanical properties of the majority of pfp systems can be derived from standard materials test procedures performed either on the pfp material itself or on the enclosing or encapsulating medium, as appropriate. However, there are no standards prescibed by which to judge acceptability or fitness for purpose. With the wide range of values of any given property across a diverse range of materials, it would be impractical to define such a standard without reference to the material(s) involved.

Similarly, chemical stability would need to be assessed uniquely according to the chemical composition of the material(s) in question. The results would require interpretation in terms of effect on mechanical properties and/or potential for reaction in a fire (eg intumescent or char forming capability). In all probability, direct assessment of the property in question would provide a more acceptable and pragmatic solution, although chemical analysis would be valuable in determining degradative mechanisms.

5.2.5 Ageing

Ageing is the result of simple, time-based change, isolated from the effects of environment, but which may manifest itself as, for example, changes in properties as discussed in Section 5.2.4. Rains [20] suggests a procedure to monitor ageing effects, but it seems fairly certain that this would more properly be described as weathering. The effects of weathering (q.v., Section 5.2.6) are probably of more practical significance.

5.2.6 Weather Resistance

Weathering is the result of exposure to environmental conditions. In the present context, a range of combinations of the various elements that make up the maritime climatological state have to be endured. In general terms, there is wide acknowledgement [21,25,33,40] of the need for a high resistance to weathering . Blake [17] states that "materials must have a long effective life under the range of environmental conditions experienced offshore" and elsewhere [43] there is reference to durability and weathering resistance (via BS 8202 Part 2).

Ideally, a fire protective coating should last the lifetime of the unit that it is protecting, in many cases this could equate to the projected lifetime of the platform, but there are no formal

Contents

definitions of what this time-span might be. Furthermore, there is no unequivocal means of predicting that the required measure of weather resistance can be attained from any laboratory tests.

BS 8202 Part 2 [24] (draft) relates to intumescent coatings on structural steel. It includes a number of accelerated weathering regimes (Table 5.1), to be carried out in a piece-meal fashion, and followed by a fire test. For "satisfactory durability" it is stated that the weathered specimen should have a fire resistance time within 25% of the fire resistance time of a control specimen and not exceed the usual maximum temperature limit within 54 minutes. It is noteworthy that for "natural exposure" a 2-year real-time exposure to an "industrial" or "marine" environment is specified. Thus no attempt is made to synthesise an accelerated weathering programme for these situations.

The Underwriters Laboratories [44] conduct a similar series of tests (see also Table 5.1), but this is not necessarily directed primarily towards intumescents.

Very little test work has been published on aged intumescent coatings. Steel panels with thin film coatings of some early versions of commercial products were exposed in Southern England [45]. Frost damage was noted but the effect of other climatological elements was uncertain. In a different exercise involving a proprietary epoxy intumescent product in a weathering programme claimed to give the equivalent of 10 years exposure, an unchanged fire performance was reported [41].

There is no similar method dedicated to assessing the durability of cementitious products. Wesson [31] proposes that 20 years service is required for protection on rail tankcars, without dusting, flaking, chipping, cracking or spalling. Van Dyke [32] proposes that there should be not more than 10% loss of properties after the equivalent of 15-20 years accelerated weathering. In a screening programme, Levine [19] has fire tested after 14 days cycling between -40°C to +60°C at 95% RH.

Shell Research Limited is currently operating a maritime test site at which the climatological conditions have been shown to match closely those of the North Sea. A number of fire protective coatings of different types are undergoing real-time weathering and their performance is monitored periodically via fire tests and mechanical tests.

Whilst real-time exposure to appropriate conditions ultimately provides a definitive assessment of the long-term durability of pfp, a reliable, multi-faceted, accelerated weathering programme is needed by the industry in order to gain confidence in materials and systems intended for use offshore. This is particularly important where there is a need to exploit potential benefits of new, untried products.

Contents

In order to fulfil this need, the design of a dedicated weatherometer, its operating programme and the back-up, real-time, exposure programmes would have to be started as soon as practicable. In particular, it is highly desirable to make an early start on generating data from carefully monitored, long-term, real-time weathering experiments that are carried out under near, or actual, offshore conditions. For the weatherometer, by careful selection of appropriate "weather elements" - rain, ultraviolet light, freeze/thaw, etc., and relevant acceleration factors - frequency, intensity and temperature (Arrhenius relationship), it is theoretically possible to condense one years' weathering in a given environment, such as the North Sea, into about one month. Care has to be exercised in creating an accelerated effect to avoid activating processes which would not normally operate in a natural weathering cycle. Confirmation or re-appraisal of the overall scaling factor would be sought from the real-time data.

5.2.7 Abrasion and Erosion Resistance

Passive fire protective systems frequently present a surface to the surroundings that has to withstand local, moving contact with foreign bodies and the erosive forces of wind, jetting air, gas or liquids, and airborne particulates. Some fire protective materials are quite susceptible to such forces but tough topcoats are usually provided (see Section 5.1.7). Resistance to abrasion and erosion appear to have attracted little attention in the literature; Stumf [46] notes that although the air erosion resistance of sprayed fibrous materials is generally good, some manufacturers recommend the use of a surface sealer.

The provision of a tough topcoat provides a practical solution in many cases; exactly what mechanical properties this should possess in addition to those necessary to perform other functions such as weather protection, have yet to be defined. Where local abrasion is a problem, an expedient may be to install some other form of cover, such as a rigid plate or flexible mat which need not possess any particular fire-resistive properties.

5.2.8 Resistance to Hosing, Cleaning Agents and Process Fluids

The likelihood of a passive fire protective coating being exposed to assault from one or more of these agents varies with location on the platform and the operations in hand. Again the situation is handled, in most cases, by provision of a topcoat (see Section 5.1.7). Whilst the effect of individual agents can be examined [25], with the dozens of cleaning and process agents in use on a platform, it would be a difficult task to specify overall "resistance" except in general terms [17,35] e.g. detergents, amines, glycols, metal soaps, chlorinated solvents, inorganic acids and alkalis. The measurement and expression of resistance would need to relate to, say, a mechanical property, tensile or flexural strength, and/or a physical phenomenon such as diffusion or permeation.

Contents

On the more general topic of washing down, Van Dyke [32] states that this process should not lead to cracking or debonding. Clark [47] comments that leaching and scrubbability are not normally tested by the Underwriters Laboratories. However, there is a Federal test which uses a weighted brush and abrasive and the surface is visually examined for scoring. He also notes that water resistant coatings must be tested in combination with the passive fire protective material.

One property that is consistently mentioned is resistance to oil ingress. Ideally this would also include resistance to ingress of diesel, kerosene, condensate, etc. These are all hydrocarbon mixtures that differ in volatility and solvating power; the latter principally depends on the aromatics content. Wesson [31] attempts to cover the field by referring to "petrochemical spills and fumes". Apart from the potential for solvent attack of a coating or the bulk pfp, absorption of quantities of hydrocarbons would provide a reservoir of fuel in the event of fire. Whilst this may not affect significantly the fire resistive properties of the pfp itself, it could assist escalation of a fire by promoting flame spread across the surface of the pfp. This aspect does not appear to have been addressed in the literature.

5.2.9 Impact Resistance

The chance that some portion of exposed surfaces of passive fire protective systems, on structural members, walls deckheads and roofs, will suffer some form of impact and be damaged is high. There is an almost unlimited range of potential impact sources and energies and it is quite unreasonable to expect that any system will emerge unscathed from a massive impact from, for example, the mis-judged swing of a load on a crane. Likewise, repeated small impacts, say scuffing from boots, will soon destroy a coating system and vulnerable areas are usually protected by kick plates. What is left in between these extremes still presents a wide spectrum of impact loads.

Impact resistance may be assessed by measuring indentation and/or energy absorption in a drop-weight test carried out on a coated plate or structural section. Alternatively, supported or unsupported specimens of coating can be subjected to a Charpy type impact. There are no acceptance criteria for results from either test. One of the difficulties is deciding upon acceptable modes of failure. Comparable energy absorption may be accompanied by a small amount of local damage and extensive disbonding in one system and by intense local destruction but leaving the surroundings intact in another. The first system would probably be immune to small impacts but liable to delaminate at higher loadings, whereas the bulk material of the second system may remain intact following a heavy impact and yet show every small knock and scrape.

Localisation of damage is advocated by Blake [17] and Dunk [25] quotes an isolated value of 6.7 J for the impact strength of an

Contents

epoxy coating, but this is not referred to a particular coating thickness. In-house measurements by Shell Research Limited show that both cementitious and intumescent materials, supported on a rigid backing plate, show surface damage from drop-weight impacts (20 mm diameter hemispherical tup) of only a few Joule but disbonding requires an order of magnitude greater.

The possible range of response makes the definition of acceptable damage, as far as mechanical integrity is concerned, rather difficult. However, given that in many cases, a breach of the surface provides a route for deterioration via weathering and/or attack by various agents, then this in itself becomes a criterion (see Sections 5.3.2 and 5.3.3).

5.2.10 Thermal Insulation

Inevitably, materials selected for their intrinsic thermal insulation capability in order to provide protection against an incoming, aggressive heat flux, will also act as thermal insulation to maintain comfortable working conditions [46] in normal circumstances, say, on an accommodation module wall. Roberts [40] notes that passive fire protection on LPG vessels may inhibit normal operations of vapour offtake; a parallel consideration may apply to blow-down of a protected vessel offshore. Work Package FR7 deals with the effect of pfp on blow-down in a fire situation.

5.2.11 Low-Level Heat Resistance

In a number of situations on a platform, structures, vessels, pipework, etc. may operate at temperatures higher than ambient or may be subject to low-level incident radiation, typically from the flare. Larsen [33] notes that application to substrates, such as a riser, running at 100°C may be necessary and that some materials begin to react at 60-70°C. It is highly undesirable if products that react to heat, such as intumescents, are triggered by low level heat from normal operations and it would be necessary to ensure that candidate materials had a suitable temperature threshold or to provide some additional thermal barrier.

Cementitious materials may rely to a greater or lesser extent on the liberation of absorbed water to extract and divert heat from the incoming flux to provide the intended level of protection. The partial pressure differentials resulting from temperature gradients across an insulating medium could influence the distibution and overall concentration of water within the system and hence affect the response to fire.

In any event it is obvious that exposure to low-level heat should not impair the activation characteristics (Section 5.4.7) or interfere unduly with the heat absorption mechanisms (Section 5.4.8) such that the fire performance is adversely reduced below a level that can be adequately forecast.

Contents

5.2.12 Corrosion Aspects

Corrosion of steel (and other materials) under coatings of various sorts is a serious problem. This is particularly so when the coating can not be readily removed for inspection. The processes of corrosion require access of water and oxygen to the steel and coatings may aid this process by permitting access and sustaining intimate contact at the interface and/or by providing a source of aggressive species that promote reaction. Conversely, coatings can exert a protective action via their influence on pH or by presenting a strongly bonded barrier of low mass diffusivity.

Except where the coating itself forms a barrier, an effective anticorrosion barrier must be interposed between the coating and the steel (see Section 5.1.1).

Most products incorporate mechanical retention systems, for example, mesh reinforcement on welded pins. For obvious reasons it is similarly important that these components are not allowed to deteriorate. All-round protection for such items should also be incorporated, for example, PVC coated wire mesh may be used.

In the special case of riser protection, where close proximity to or periodic immersion in sea water occurs, the case for an essentially water-tight system is considered paramount, since the consequences of corrosion and failure are potentially disastrous (para.19.22, Cullen report [1]).

Non-destructive techniques for assessing corrosion beneath pfp are not totally reliable. Where conjunction with internal inspection of pipes and vessels is possible, methods such as ultrasonic scans and radiography may have more success. For external examination, it is necessary to remove at least selected areas of pfp in order to gain direct access to the substrate.

Assessment of the potential for promoting or inhibiting corrosion can be derived from real-time or accelerated weathering programmes (see Section 5.2.6) using specimens of appropriate configuration which are sectioned for assessment.

5.3 Maintenance

Although the systems in question are designated "passive" it is a gross mistake to assume that they are entirely unchanging or unchangeable and that they can be installed on a totally "fit-and-forget" basis. Most are not single component systems but comprise a number of discrete elements that must operate as an integrated whole for maximum performance.

Since the intrinsic properties of the various components are essentially fixed and deterioration can not be reversed, maintenance revolves around inspection, recognition and replacement of defective components or sections. Deterioration

Contents

can occur as a result of weathering, accidental damage or modifications to structure or plant.

At the most basic level, positive identification of which product or system is installed may be essential for determining appropriate action. For some of the older, existing installations this facility does not exist.

5.3.1 Inspection

The frequency, extent and method of inspecting passive fire protection will vary according to the type of system and where it is located. Inspection intervals of 5-7 years have been mentioned [31], but intervals of 2-3 years may be more appropriate for particular systems. Particular attention should be paid to the specific effects of local work activities, environmental exposure and services/trades activities.

For a totally encapsulated system, attention would probably concentrate on edge seals with a visual assesment of cladding integrity. Examination of the physical state of the protective medium would be relegated to ad hoc observations, say, when making a penetration.

Similar abbreviated inspections would probably be applied to internal, B-type partitions, perhaps with increased attention to examining for continuity across hidden spaces (false ceilings, etc) to ensure integrity in terms of resistance to passage of fire and smoke.

Sprayed-on coatings and prefabricated panels and shells, particularly those exposed to weathering, probably require the most critical inspection. The topcoat in particular must be maintained in effective condition and both environmental and accidental damage identified for timely correction before progressive deterioration impairs the design level of protection. Consideration must also be given to identifying the need for local repair of the bulk protective agent.

Inspections should also include the general condition of the protected substrate. If, for example, a bulkhead or beam has been deformed by some form of overload and is not to be replaced, then close attention should be given to the integrity of the interface between substrate and coating.

5.3.2 Recognition and Significance of Defects

Inspection must rely heavily on visual observation and, although primitive, much can be gleaned by tapping, brushing and probing the surface of coatings. Currently, there appear to be no instrumental or automated techniques that can universally replace manual methods.

Contents

The recognition of defects and appreciation of their significance plays an important role in the pursuit of a successful maintenance programme. Some at least of the required expertise could probably be gleaned from manufacturers, applicators and materials specialists. No information has come to light from the literature.

Defects may be present or develop from the time of installation. Those that occur at the time of installation could be anywhere throughout the system from substrate to topcoat, but should be detected and rectified via an effective quality control system. Defects occuring later as a result of accidental damage, making cut-outs, weathering or other ravages of service conditions, may require an extra diligence in registering and taking effective action.

Whilst surface damage arising from an impact may obviously require, say, some filling-in of the bulk coating and re-covering with topcoat, examination for hidden defects, such as disbonding from the substrate or the effects of any water ingress is also important. Trial excavations may have to be made to confirm that the system remains sound or otherwise.

5.3.3 Repair; Topcoat, Bulk, Substrate / Interface

The need to repair a pfp system may arise through accidental damage or deliberate breaching, removal or hot work during modifications (Sections 5.3.4 and 5.3.5). That it should be amenable to repair (or modular replacement) is a fairly obvious requirement [21].

Topcoat repair could be a relatively simple task of painting. However, the condition of the underlying material, particularly with respect to absorbed water and/or contaminants such as oil, salts and detergents must be considered. The nature of the surface to be coated is also important. A number of systems incorporate reinforcing filaments and fibres and care must be taken that these do not create multiple, microscopic breaches in the overlying film.

Small-scale repair of the bulk material can often be accomplished by building up to thickness with a trowelling grade version of the original. Larger-scale repairs may require replacement of retaining mesh.

Substrate and interface repairs would probably require specialist services and reinstatement of the passive fire protection system would imply that normal installation conditions should be applied (Section 5.1).

Contents

The reputable manufacturers supply details of what is required for repair of their particular system. The details include cutting back defective material, treatment of cut surfaces, re-priming, fitting and tying in new sections of retaining system and topcoating.

5.3.4 Removal and Modifications

Blake [17] has commented that passive fire protection should be readily removable for making penetrations and Van Dyke [32] offers a sand/water jet for local removal of a coating to facilitate inspection. It is inevitable that such activities or other disturbance, say, to modify steelwork, will be required. Therefore it is important that removal should confine disruption to the local area and the system should then be amenable to conjunction with some interfacing arrangement (e.g. a proprietary penetration seal) or full reinstatement.

5.3.5 Hot Work Tolerance

Steelwork modifications invariably require hot work, either cutting or welding. Whilst it may be obvious and essential to cut back a fire protective coating to gain access, it is not necessarily clear what effect hot work has on material remaining in the vicinity. Primers and/or bulk material could be adversely affected and no guidance is evident on what precautions should be taken or what should subsequently be examined and/or reinstated. The uncertainties could be more acute where work has been carried out on an unprotected face, i.e. the opposite side to which passive fire protection has been applied. For bonded systems, i.e. those employing interfacial paints and primers, where the hot work has raised the substrate temperature significantly, careful excavation and local reinstatement of the full system (see Sections 5.1 and 5.3.3) is the only means of ensuring total integrity.

5.4 Fire Performance

The need for a realistic fire test has been stressed by Cullen [1], para.19.101 and he has recommended that a recent DEn discussion document on Fire and Explosion Protection [48] should be withdrawn (para. 19.102) on the grounds that it is not compatible with the emerging strategy for obtaining better information on the behaviour of pfp in "real" fires.

Historically, "fire performance" has meant performance in a standard, furnace-based fire test, as distinct from performance in an actual fire, and this has been virtually the sole governing measure of acceptability for a pfp system. The fire performance of a particular medium can not be assessed in isolation, it must be installed on a representative substrate or structure to enable it to be subjected to a standard fire test. The test specimen is

Contents

constructed as a part or the whole of one face of a purpose-made furnace, or it is produced as a structural element that is wholly contained within a furnace. The furnace is programmed to follow a defined time/temperature curve which may be a "cellulosic" or "hydrocarbon" type (see Figure 5.1). In Sections 5.4.1 - 5, comment is provided on selected aspects of conventional fire testing.

5.4.1 Protection; Stability, Integrity and Limited Temperature Rise

The acceptance criteria for systems subjected to standard fire tests are well known and an outline is given in Section 4. The requirements for maintaining stability and load-bearing capacity are fundamental to the design functions of both structural steel and bulkheads. The requirements for integrity, i.e. resistance to the passage of flames and hot gases that could spread the fire, and to the passage of smoke and toxic fire products that ultimately become life-threatening, are of particular importance for a protected area, such as an accommodation module, which must serve as a refuge.

Pfp applied to a structural steel member serves to extend the time taken for the steel to reach a given temperature. In a totally enclosed system it can not prevent the steel ultimately reaching the same temperature as an unprotected member in the same environment. For a system that is not totally enclosed, e.g. pfp applied to a bulkhead with an unexposed face in the free atmosphere (an infinite heat sink), the time taken for the unexposed face to reach a certain temperature is similarly extended and the ultimate temperature achieved will be lower than that for an unprotected bulkhead.

The limitation of temperature rise is of direct relevance to stability in the case of structural steel and to the generation of intolerable conditions in the case of partitions, either by direct transmission of heat or by decomposition of materials on heated surfaces. The results of calculations to illustrate the importance of the latter aspects for a fire-engulfed module are quoted in Section 19.29 of the Cullen report [1].

5.4.2 Influence of Test Material on Heat Input to Furnace

Consideration of this factor illustrates where a direct requirement for pfp fails to reflect the true performance of the test material. In the standard fire tests, the intention and practice is to maintain specified temperature conditions within the furnace to provide the reference, test environment. This is done irrespective of the behaviour of the test materials. It means that materials which contribute combustible products to the fire are favoured by reducing the primary heat input, and those which feature heat absorption mechanisms are penalised by a corresponding increase in primary heating. The latter situation has been noted specifically by Bond [49] in conjunction with an

Contents

assesment of the resultant furnace heat input in tests of water filled columns with large thermal mass.

It is fundamentally wrong that the behaviour of a test specimen should be allowed to influence the test conditions, either adversely or advantageously, such that the applied test load becomes a variable quantity and yet is taken as being constant.

5.4.3 Resistance to Hose Stream / Deluge

It has long been maintained by various sources that a valid test of a fire protective material is that it should withstand the action of a directed hose stream immediately following a fire test [17,26,32,37]. The argument for this is that a coating system should be able to survive the action of a platform deluge and be able to resume its function as a protective agent should the water system fail and a resurgence of fire ensue. On pressure vessels where the need to apply cooling water is probably more critical, the requirement for no spalling [31,40] carries a stronger argument, but there appears to be no concession to the likely means of delivery, i.e. hose or deluge.

What does not seem to be widely appreciated is that the "hose stream test", as originally conceived, was intended simply as a means of demonstrating resistance to puncture of walls and doors by providing a mechanical load [50]. It was not intended as a test of fire-exposed, fire protective media. Nevertheless, the application of a hose stream at intervals between firing has featured in SINTEF jet fire tests [51].

5.4.4 Response to Thermal Shock

Response to thermal shock has largely been associated with cooling by a hose stream, as in Section 5.4.3. Wesson [31] has specifically noted that thermal shock may arise from simultaneous exposure of adjacent areas to spillage of cryogenic liquid fuel gases and to flame.

Thermal shock may also be experienced at the initial impact of a hydrocarbon fire and during subsequent, rapid fluctuations of heat flux in an engulfing flame. That these conditions can not be effectively produced in conventional furnace tests contributes to the incentive for investigating other fire sources as the basis for more realistic testing (see Section 5.4.12).

5.4.5 Geometric and Orientation Effects

Geometric effects are taken into account to a certain extent in the selection of specimens for fire testing. The Section Factor (H_p/A) concept, which includes some consideration of the degree of exposure, also relates to specimen geometry. However, in the conventional fire response assessment, a diffuse heat source is constrained to be presented to the specimen in an essentially uniform fashion. In "real" fires, the heat flux distribution on a

Contents

given element may be far from uniform. Furthermore, in fires where there are high gas velocities and a significant convective component, the geometric effects and orientation of the target and the characteristics of the flame may assume further importance with regard to the distribution of incident heat flux (see Work Package FL1). As an example, an engulfing jet fire (see Section 5.4.6) impinging normal to the flange of an I beam is likely to have a different effect to a comparable jet impinging at an acute angle into the web/flange channel. Some indication of this has been observed in large-scale experiments [52,53]. See also SINTEF's findings in Section 5.4.6. These effects can not be examined in standard furnace tests.

One further point concerning the standard tests is that whilst roof sections can be tested in a simulated "fire from below" situation (reflecting the needs of conventional buildings), there exists no direct means of testing flat roof assemblies for resistance to fire from above, such as might be experienced by an offshore module. Possibly as a consequence of this, pfp for a roof may be specified as required internally (where it can be certified) and not specified externally (where it can not be formally certified). Nevertheless, in some cases operators do specify external protection for the roof [54]. The provision of external pfp for an accomodation module roof, particularly around and including the housing over a lift shaft, would improve protection against a large plume from a blow-out fire or against fire on a superposed helideck.

5.4.6 Resistance to Jet Fires

Caveats associated with the description and characteristics of a jet fire have already been expressed in Section 2.2. These accepted, consideration of the requirements for resistance of pfp to jet fires and the work carried out in this area can be explored.

A jet fire results from the ignition of a release of pressurised fuel (see Work Package FL1 for a full description of the range of jet fires considered). The fuel may be predominantly gas or liquid or a two-phase mixture; it could also contain particulate solids. Depending on the composition of the fuel and the source pressure and the orifice geometry, the resultant flame may exhibit characteristics ranging from highly energetic and directional through to a more lazy flame, hardly distinguishable from that of a pool fire.

The possibility of such fires has been recognised for some time. Unfortunately, their potential severity has been disguised, in part, by an early tendency to refer to them as "torch fires" which tended to give a naive impression of something relatively small that had only a local influence. Consequently, in some quarters, their importance was all but dismissed. The reality is that a jet fire of sufficient magnitude to engulf a whole module or a substantial part of a platform structure (as in the case of Piper

Contents

Alpha) is quite feasible A review of studies made on experimental jet fires is given in the report on Work Package FL1; some work has also been published externally [55].

Experimental jet flames have been used to quantify the impact experienced by targets impinged upon and engulfed by the flame. Heat flux density measurements have been made at various points on the targets within and outside the flame envelope to determine the convective and radiative components.

The maximum heat flux experienced by an object in the flame may vary with the size of the flame, the size of the object, its shape, and its distance from the source. It may be on the face opposite to that upon which the jet impinges. The flame conditions are established almost instantaneously on ignition, presenting a large thermal shock to an engulfed body (this contrasts markedly to conditions experienced in a furnace).

Passive fire protection is possibly the most important practical defence against an impinging or engulfing jet fire. There is concern that water jets and sprays may not penetrate sufficiently to provide effective cooling and leave unwetted areas where temperatures could rise rapidly to critical levels. Work done for the Federal Railroad Administration by the Department of Transportation (DOT) at the Ballistic Research Laboratories (BRL) (described by Van Dyke [32]) used "torching" tests in an extensive evaluation programme of candidate systems for protecting rail tank cars (see also Section 5.4.12).

Ideally, passive fire protection systems should be able to withstand the initial shock of impact of a jet fire and the subsequent effects without cracking, spalling, delaminating or eroding in any way that significantly reduces the level of protection. A jet fire is a particularly severe test of an intumescent system which must resist excessive distortion and shear in the partially-mobile phase and disruption of the char induced by fluctuating aerodynamic forces.

There is at present no formal requirement that pfp intended for offshore applications should withstand jet fires, although such tests have been carried out on behalf of certain manufacturers and operators. Work is currently being carried out by Shell Research Limited [52,53,56], FRS and HSE in the UK, and by SINTEF in Norway [57] on the response of various passive systems to jet fires.

The Shell Offshore Flame Impingement Protection Programme (SOFIPP) [52,53,56] resulted from an urgent need, in the wake of the Piper Alpha disaster, to investigate the behaviour of full-sized structural members in a full-scale hydrocarbon jet fire. A wide range of jet fires fuelled with methane and LPG gases had been characterised in earlier studies [55]. A methane flame about 20 m long and 2 m diameter, resulting from a mass flow rate of 3 kg s^{-1} discharged at 60 barg, was selected.

Contents

This demonstration programme, which was not intended or presented as a formal test, was organised to investigate the capability of passive fire protection to withstand the impact of a large jet fire and to extend the survival time and serviceability of a structural member exposed to such a flame. Two, well-established, proprietary products, one cementitious and the other an epoxy intumescent, were applied to the manufacturers' best assessment of thickness required for the given scenario. Based on the steel temperature reaching an arbitrarily selected value of 300°C, survival times extending towards and beyond one hour were achieved, compared with only two minutes for an unprotected specimen.

Parallel exercises have since taken place in which structures representative of risers and of ESV's, each with candidate, passive protective systems, have been subjected to similar, large, long-duration flames. None of these results has yet been published in the open literature, but it is fairly clear that testing a complete (and probably full-size) assembly, rather than component units, is necessary to obtain a fuller appreciation of its response.

The SINTEF facility comprises a lance fuelled with propane at a pressure of 2 barg, discharging gas or mixed gas/liquid at about 100 g s^{-1}. The flame, which is about 5-6 m long, is aimed at a target placed typically within the range 0.3-1.5 m from the orifice (see Work Package FL2, Sections 9.7.3 and 9.7.4). Certain proprietary pfp products coated onto a 2.2 m square flat plate substrate have been subjected to long-duration impingement of this flame, some with interludes in which a water stream has been applied to the hot face of the coating [51]. However, not all the results are available in the open literature.

SINTEF have also carried out tests with a sonic propane jet flame, with a total output of 12 MW, impinging into the channel of a large I-beam section, creating intense recirculation and effectively increasing the optical thickness of the flame. This produced a heat flux up to twice that of a standard hydrocarbon fire furnace test (see Work Packages FL1 and FL2 for further details). The high flux and the recirculation of the flame in and around such a structure could have significant influence on the response of a pfp coating applied to a target (such as a pipe section) exposed in this zone. Other targets, such as plates, may cause considerable change in the recirculation patterns, thus altering the test conditions, and this must be considered in any developments.

There is considerable interest in the behaviour of jet fires and the response of pfp to them. The possibility of characterising the fire response of pfp via use of a jet fire is attractive in that there is scope for defining and controlling the fire parameters independently of the surroundings, provided that external effects such as wind are excluded, leading to an enhanced potential for the test to be reproducible. Furthermore, control

Contents

of a jet fire assembly would not necessarily need to rely on feed-back from the target area, therefore the behaviour of the specimen would not influence the fire source in a manner other than that which would occur in a "real" fire. Overall, it is conceivable that the conditions produced in a jet fire test (or a co-ordinated set of tests) could ultimately be related to a realistic fire scenario that represents, with regard to combined intensity, impact and duration, probably the most demanding hydrocarbon fire situation. Such a test could also provide a conservative solution to the needs of less-demanding hydrocarbon fire situations or cellulosic fires.

5.4.7 Activation Temperature

There is no formal requirement that a system which reacts to heat, such as an intumescent, should have any particular activation temperature. Obviously it should not be too low since tolerance to temperatures generated under normal operating conditions (Section 5.2.11) and tolerance to hot work (Section 5.3.5) would be impaired. On the other hand, if activation requires high temperatures, then the rest of the system would have to be capable of dissipating the incoming heat flux to limit the temperature rise on the unexposed face until the full heat absorption mechanism came into play.

A further question concerns whether, once activated, a reacting system should be self-sustaining or require continuous external input. The latter situation is to be preferred, since it provides something more than a "one-shot" capability.

5.4.8 Thermal Properties

It has been stated that the thermal conductivity of a fire protective system is the most important parameter [21], and indeed it is of fundamental importance. However, depending on the system in question, it could be more informative to consider its thermal diffusivity (thermal conductivity / density * specific heat), an expression of the ratio between heat transmitted and heat absorbed. This is particularly important for initial exposure to a fire, before steady state heat transfer is established through the system, and when the principal activities that generate the valuable time delay come into play. Individual diffusivity parameters relating to each component of a multi-component system will require consideration and since each may be temperature dependent, it is not feasible to assign definitive values.

Heat absorbed in reactions or phase change represents a major, thermal heat sink. The thermal response, including evaporation of water, may be defined for certain salt systems. However, the water content of other cementitious products will vary with ambient conditions, therefore the thermal properties before and during the evaporative phase will vary on a more complex time basis. In the case of intumescent systems, heat is absorbed in the pyrolysis of the matrix material and in the activation of the

Contents

spumific agents and rejected from the system in the transpiration of hot gases.

The radiant heat flux incident on a pfp system exposed to a fire, but not within the flame, may range from a few kW m^{-2} to several tens of kW m^{-2} close to the flame envelope. For a structure engulfed by a flame of sufficient optical thickness (see Work Package FL1), the average total flux may be several hundred kW m^{-2}. There will also be a convective component. Therefore, pfp has to cope with incident fluxes ranging over at least two orders of magnitude. The temperature generated at the surface of the pfp is a function of the incident flux and the radiative properties of the surface, the convective heat transfer coefficient at the surface boundary and the heat losses into and through the system. The temperatures generated, with time, elsewhere throughout the system result from operation of the heat transfer mechanisms outlined above.

5.4.9 Non-Combustible Materials

Within the regulations governing offshore structures, the requirement for using materials that are essentially non-combustible, consistent with their intended function, is prominently stated. The criteria for judging combustiblity vary slightly with different standards and test methods [2,6,58,59], but all are based on heating a specimen to 750°C. The Norwegian requirements [21,60,61] for offshore installations are based on the same standards.

If fire protective systems contained no combustible materials, there could be no spread or development of flame (although heat transfer could still occur). In practice, however, combustible materials and components are used. For example, mineral wool is often formed with an organic binder: cementitious coatings are invariably protected from weathering with a polymer paint topcoat: intumescent materials burn to a certain extent throughout their bulk in order to produce a heat-resisting char.

Whilst compliance with the ideal of non-combustibility would be desirable, strict enforcement would be to the detriment of fire protection, as the situation exists today.

On the other hand, overall passive fire protection is likely to be enhanced by adoption of tighter limitations on the use of combustible veneers and the use of ignition resistant and low flame propagation materials [62].

5.4.10 Smoke and Toxic Gas Production

Smoke and toxic gas production is strongly linked to the organic content of the passive fire protective system. The source may be the bulk material (intumescents), topcoat, sealant and caulking mastic, binder, retaining mesh coating, adhesive or primer. In an enclosed, fire-engulfed module, human survival time will be linked

Contents

to the generation of intolerable conditions as a result of build up of temperature and its effect on materials (Cullen [1] para. 19.29).

The ideal is no smoke and no toxic products liberated either on direct exposure to fire or in a situation where the substrate is heated by fire remote from the protected face. Whenever organic materials are involved in fire, CO and CO_2 will be produced at a rate and in proportions that are dictated by the fuel, the fire and ventilation conditions. Their production must be viewed in proper context and the likelihood that the primary fire source is producing the same gases (and others?) at a far greater rate [25] must be considered. Probably of more practical significance is the concept of avoiding production of "super-toxics" such as HCN (and possibly HCl, but more from the point of view of its corrosive action). Smoke production also should be viewed against the potentially more vigorous output of the primary fire and other secondary sources such as paints, veneers and furnishings.

It is current practice to exclude intumescents from use inside enclosed, normally manned spaces on platforms (accommodation and control rooms). The argument is that these areas should serve as refuges in emergency and that an external fire could heat up the coating from the rear face and initiate decomposition. Landro [21] tolerates smoke and toxic gas emissions wherever they constitute "no significant increase in risk". Thus in freely vented, external locations, the problem is much reduced.

Comment has been made on the desirability of quantifying toxic gas emissions [33,47] and to provide a ranking of materials, but no standards exist. This problem also arises in respect of materials other than pfp. Such a ranking would require a complex description of rate of emission for each toxic agent as a function of time and fire conditions, coupled with a reliable assay of toxic potency, plus heat stress and any synergistic effects. At the end of the day, it is quite probable that, in any event, toxic effects would be dominated by CO emissions. The nearest practical ranking (Toxicity Index) is based on a static analysis and proportional summation of the concentration of selected gases with respect to lethal dosage (NES 713) [63]. In the UK, the Central Electricity Generating Board [64] used a similar procedure based upon incapacitation rather than lethality.

FRS is currently working on a more sophisticated fractional dose model and a multi-client programme aimed at developing a dynamic analysis system and model has recently been announced by Rapra Technology Limited. It is hoped that these initiatives will provide a framework for relating the attainment of critical toxic conditions to fire history.

5.4.11 Sudden Failure of Spent Material

The temperature of a structural element controlled by passive fire protection tends to rise steadily on exposure to fire. The rate

Contents

of rise may vary, perhaps passing through a water plateau, but nevertheless a smooth curve results. A sudden reduction of protective capability, through loss of coating or char is an undesirable event, since local, rapid rise of temperature will ensue. Mechanical retention systems tend to guard against this possibility and obviously they should remain secure. It is important that loss of protection does not occur as a result of a sharp cut-off in properties as the material becomes spent since this would become self-propagating and have a more global effect on the structure as a whole. This could result in a rapid change in conditions which, for example, might negate the possibility of escape.

5.4.12 Non-Standard Fire Tests

Perhaps the best known non-standard fire test is the Mobil Fire Box described by Warren and Corona [65]. This comprised an open-topped brick chamber approximately 1.1 m x 1.8 m x 1.2 m high with a single, liquid propane fuelled burner located centrally in the base. The flames were directed onto the walls of the chamber avoiding impingement on the specimen. Test specimens were mounted either on or within the upper section of the chamber. This assembly produced a high rise temperature profile within the furnace cavity that came to be known as the Mobil curve, which was the forerunner of all subsequent "hydrocarbon curves". In operation, the peak total heat flux generated was reported to be 5.4 cal cm^{-2} s^{-1} (226 kW m^{-2}), with 3.2 cal cm^{-2} s^{-1} (134 kW m^{-2}) convective. The total flux is considerably higher than values determined from pool fire experiments which range from 80-160 kW m^{-2} (see Work Package FL1, Table 6.4). It should be noted that this test was not specifically developed to simulate a pool fire; it was originally described as one that "realistically simulates the environment in a petroleum fire". It is, however, a compartment fire rather than an open fire.

A "pool fire" test facility is operated by Darchem Engineering Limited [67]. An array of LPG burners with a total output of 3.5 MW is used to simulate a hydrocarbon pool fire with a rapid, initial temperature rise derived from direct flame impingement. The maximum "flame temperature" (see Work Package FL1, Definitions) is reported to be 1100°C. The commercial literature indicates up to 6 burners directed onto selected faces of targets providing impingement over substantial areas but not necessarily total engulfment. Whilst this assembly would appear to have some practical merit, it would also seem difficult to ensure that a reproducible, characterised fire environment is presented to specimens having different configurations.

Pool fire tests have also been carried out as part of the US rail safety programme [66] using 1/5th-scale and full-scale loaded rail tank cars engulfed by kerosene pool fires. Although the reproducibility of the tests was deemed poor, the outcome of the whole investigation, which culminated in a Federal Regulation [68]

Contents

defining performance criteria, was judged by subsequent events to have been successful [69].

Roberts [70] has reported on tests involving a protected LPG tank subjected to a kerosene pool fire and Rains [20,71] has commented on a proliferation of pool fire tests, some quite ill-defined.

Pool fire tests that use actual pools of liquid hydrocarbon as the fuel source suffer from two major drawbacks. The first is that, once ignited, there is virtually no control over the fire. Secondly, fires of significant size are usually conducted outdoors and the direction or tilt of the flame, and hence extent of flame engulfment, can be strongly influenced by wind. Both factors lead to poor repeatability and reproducibility.

The use of the BRL/DOT torch tests has been described briefly in Section 5.4.6. The facility comprised a large (1890 litre) reservoir of LPG immersed in a steam heated water bath to maintain the necessary drive pressure to control valves for either liquid and gas offtake, or both. The conditions eventually selected were an orifice diameter of 9.5 mm and a source pressure of nominally 1.6 MPa, giving an estimated mass flow rate of the order of 1 kg s^{-1}. One form of target used to evaluate passive fire protection materials comprised a 1.2 m square steel plate, fitted with thermocouples on the unexposed face and backed by an insulated enclosure. Full-scale tank cars with LPG cargos were also subjected to the torch test [66]. At the flow rates indicated, it is likely that only a portion of the tank surface would be engulfed. This still provides elements of a valid test in that localised heating of a pressure vessel combined with the effects of wetted and non-wetted internal surfaces is considered a credible variation to total engulfment (see Work Package FR7).

The lack of uniformity and reproducibility of these tests, which were honest attempts to produce a fire test that bore a greater resemblance to "real" hydrocarbon fires than the existing cellulosic fire tests, directed effort towards establishing a furnace-based hydrocarbon fire test. Much attention has been given to defining a suitable time/temperature curve (see Section 4.1) and specifying heat flux criteria [72,73]. Furthermore, it was universally accepted that the furnace conditions would be controlled by feed-back via heat flux monitoring stations within the furnace. Unfortunately, the hardware available to date is unable to cope with this requirement, therefore compliance with the temperature algorithms is controlled via thermocouple measurements. However, in either situation, using heat flux or temperature monitoring, the test specimen would still exert an influence on the test conditions (see Section 5.4.2).

Another difficulty is posed by the thermal inertia of many existing furnaces which are lined with refractory brick; this limits the ability to achieve a rapid, initial temperature rise. Ceramic fibre based linings that can present a recommended [10]

Contents

thermal inertia of less than 600 W $s^{-0.5}$ m^{-2} K^{-1} tend to be less durable and require more frequent replacement. Additionally, there is some concern about possible health risks associated with the potential for forming cristobalite under certain fire conditions [74,75].

5.5 Explosion Survivability

The possibility that a fire may be preceded by an explosion or that an explosion occurs during a fire is ever present. The ability of a fire protective medium to remain essentially in place is fundamental to its potential for providing protection.

Ideally, a protective medium would absorb the energy from an explosion or impacting missile and emerge unscathed. Furthermore, it would conform fully to elastic and plastic deformations of the substrate without disbonding. Current design practice for structural units admits deformations only up to the elastic limit, i.e. accommodating overpressures of the order of 500 mb or less. It could be argued that structures that have been grossly distorted as a result of higher blast loadings would have little to benefit from pfp. In reality, however, the ideal for pfp may not be realised and a level of damage tolerance is required. Many of the aspects discussed in the subsequent sections are attributed to the work of Haverstad [76].

5.5.1 Physical State

A sprayed-on fire protective coatings makes intimate contact with the substrate therefore its response to overpressure generated by an explosion is governed, to a large extent, by the response of the substrate. If large deformations of the substrate occur, then there is a strong possibility of disbonding and break-up of the coating occuring. This holds for an explosion on either side of a coated partition or structural member. The effectiveness of any mechanical retention system is then put to the test, for although the coating may have broken into pieces, a fire protection ability may still exist, provided that some semblance of a continuous barrier remains. This may not necessarily be the case for coatings or preformed sections that are only lightly supported or make firm contact only at selected points. The reduced pressure phase of the explosion may also adversely affect such assemblies.

Crushing damage is a possibility, but this is likely to be confined to materials of low density (fibrous matrices, foams or expanded structures) or built-up systems, such as boards or panels, incorporating air gaps.

If a coating layer of high mechanical stiffness (product of modulus * thickness) is subjected to in-plane compression through bending, the associated through-thickness tensile stress may produce spalling. This results in loss of material from the surface region, which is not normally provided with a means of

Contents

retention. If bending produces in-plane tensile stresses, these may be relieved by periodic through-thickness cracking.

High gas velocities associated with the blast can cause intense erosion of the bulk material. Although this is essentially a surface phenomenon, it can literally "blow away" a coating, board or blanket medium. Surfaces that have been damaged, cracked or crushed, are said to be more vulnerable to this effect. An overlay of netting or sheet cladding may reduce this form of damage.

Impact of missiles generated by an explosion may also occur. In this case the same considerations regarding resistance and response of a pfp coating as noted in Section 5.2.9 apply.

5.5.2 Retained Protection Capability

Haverstad [76] makes the proposal that fire testing and approval of systems that have been subjected to an actual or simulated explosion precursor will follow the same procedure as used for existing, standard fire tests, with a qualification for maximum permitted overload and resultant structural response.

Concerning firstly the situation where material has been lost from the surface of a coating, provided that whatever was lost did not embody a disproportionate part of the protection mechanism, the remaining material should afford a degree of protection proportional to the remaining thickness. As a further guide, the tolerance of thickness variations noted in Section 5.1.9 could be considered.

Through-thickness cracking, as such, is generally not detrimental to fire performance. However, where it is associated with substantial loss of bulk material down to the substrate, or with extensive disbonding, it is potentially a much more serious situation. Where there has been significant loss of material or where the cracks are sufficiently wide, hot spots could be generated. To what extent such cracks can be tolerated has not been investigated. If disbonding occurs, a route could be opened for flame and hot gases to penetrate behind the pfp and the chance of accelerating the destruction of the coating is considerably increased.

Disbonding from the substrate may not be too serious a problem for performance in a fire following the explosion event. A significant degree of protection may be retained provided that the barrier is essentially intact and held in place. The protection may even be enhanced by the resultant air gap. This should not be taken to imply that the system would be eligible for continued service if no fire occurs immediately; reinstatement of the fully bonded system would almost certainly be necessary to avoid substrate deterioration in the longer term.

Contents

One pfp product [77] has been subjected to a practical demonstration in which a charge of TNT was detonated to give an overpressure of 370 mb on the protected face of a 5 mm thick steel panel. It is not clear whether the resulting deformations were entirely elastic or not, but no disbonding was observed. Immediately after the explosion, the panel was subjected to a kerosene pool fire which burned for 30 min. Whilst temperatures exceeding 600°C were recorded on the exposed face of the pfp layer, the unexposed face of the steel rose no more than 40°C above ambient. Whilst a good fire protective capability would be expected from the 100 mm thick pfp layer, it should be noted that there was no damage sufficient to impair its performance to a significant extent.

5.6 Summary of Overall Performance

A pfp system must meet a number of requirements to ensure that it is installed to a satisfactory standard with a good chance of enduring use and abuse over a prolonged period whilst retaining its intended fire performance. These may be grouped as:

Preparation, installation and quality

Resistance to mechanical, weathering and thermal effects

Inspection and maintenance

Resistance to "real" fire environments and exhibiting a restrained contribution to fire effects

Resistance to the effects of moderate overpressure from an explosion

There are few formalised requirements in any of these areas. Whilst truly critical conditions pertaining to most would be difficult to define, the setting of goals, with due regard to the nature and operation of the system in question, is a viable alternative.

Contents

6 CURRENT STATUS

The assessment of fire performance depends upon furnace-based tests.

The current, formal requirements for passive fire protection are based solely upon the performance of the virgin materials or systems. Performance is assessed primarily, in standard, furnace-based fire tests, by measuring the temperature rise of the protected element. The selection of thickness of coating material to be applied to columns and beams is based upon tables derived empirically, with reference to ranges of section factor (H_p/A), compiled for a specific product. Selection of thicknesses to be applied to bulkheads and partitions is also largely empirical. The bulk of the tabulated data has been generated from furnace tests operated to a cellulosic fire curve. Some data relating to individual tests operated to a hydrocarbon fire curve are also published in manufacturers' literature. Empirical factors are used to a certain extent to convert thicknesses from "cellulosic" to "hydrocarbon" requirements.

It has been advocated that the prescribed temperature/time furnace conditions in a standard fire test should be replaced by control based on heat flux density. However, it has not been possible to achieve this reliably. Furthermore, results accumulating from experimental work on large-scale fires are casting further doubt upon the validity of conducting tests in a furnace environment.

Response to explosion depends upon the reaction of the substrate.

Explosion resistance is strongly related to the deformation characteristics of the substrate. The fire protective capability of a coating on a deformed structural column or beam, assuming that it has remained substantially in place, may not be seriously impaired. The thermal performance of a coating on a deformed bulkhead may be similarly adequate, but the integrity of the whole assembly may suffer quite markedly if, say, fixings are excessively strained.

Smoke and toxic gas emissions are considered in isolation.

The smoke and toxic gas produced from a given pfp material involved in fire tend to be regarded in isolation. The emission of toxic products is time and fire dependent. The quantity of CO produced from the primary fire source may dominate other, potentially more toxic emissions from pfp and constitute the main life threat.

Contents

Information on installing pfp is basically good but quality is not always achieved.

The requirements for installation vary from product to product. The preparation and application detail available from the manufacturers is generally quite comprehensive but quality of installation in the field is not always achieved. Documentation covering exactly what is installed, where and when, and the production of representative panels for control and reference purposes are not always available.

Where field experience is lacking, long-term durability is an unknown quantity.

The requirements for robustness and endurance of pfp that will enable it to survive over a prolonged period, and still be serviceable in the event of fire, are not formally defined. Pronouncements are mainly of a qualitative nature along the lines of "should be resistant to...". The current generation of accelerated weathering procedures are based on selection of only one or two factors and are carried out in a piecemeal fashion. As a result, only a limited ability to predict future performance is provided. This inhibits the early introduction of new and improved systems.

Maintenance is often accorded a lowly status.

Inspection and maintenance of pfp is invariably a poor relation; fully implemented it is costly, since access is often difficult. The recognition of defects and appreciation of their significance may not be to the fore; operators would prefer "fit and forget" systems.

Contents

7. AREAS OF UNCERTAINTY

The **objective** of setting and assessing performance requirements for any system is to establish fitness for purpose.

The **purpose** of passive fire protection materials and systems is to delay or limit the effects of fire on structural and segregating elements or vital equipment. Therefore, to establish fitness, it is necessary;

(a) to **determine how the material or system performs when exposed to fire** and
(b) to be able to predict that **the material or system will be in position, in a suitable state, throughout its projected lifetime.**

NEITHER IS FULLY SATISFIED BY CURRENT PRACTICE

The conditions prescribed for current furnace-based fire tests do not relate to conditions in "real" fires.

Some of the inadequacies of the current fire tests in relation to "real" fire conditions are universally recognised, others are not so widely appreciated. Alternative test regimes are being explored but factors associated with high gas velocities, which can not be produced or represented in furnace-based tests, will probably require tests which feature direct, relatively high velocity, flame impingement.

The problems to be addressed in defining fire tests are concerned with obtaining a manageable, reproducible, well-characterised flame in which conditions can be related to those in "real" fires. It may prove necessary to generate different combinations of conditions in order to cover the range of fire events possible.

Smoke and toxic gas emissions are not addressed in proper context.

Virtually all pfp materials contain some organic components whether as bulk material, topcoat, etc, which decompose on exposure to fire. There is uncertainty about the overall life-threat significance of the resultant smoke and toxic gas emissions compared with those from the primary fire. Potential benefits may be lost by restricting the use of certain products unnecessarily.

Contents

Requirements for robustness and ability to predict long-term durability are lacking.

Better qualification of the degree of robustness (including tolerance of damage, caused either mechanically or as a result of an explosion) the expectations of endurance, and indications of how "resistance" is manifest and can be assessed are needed.

The relationship of accelerated weathering to real-time weathering in a "real" environment must be questioned. Long-term exposure to simulated service conditions coupled with a searching monitoring programme provides the ultimate answer, but this does not help the timely introduction of new or updated materials. However, early undertaking of such work is essential to form the background to reliable, multi-faceted, accelerated weathering programmes that must be developed to serve the industry as effective predictors of performance within manageable time scales.

Quality and maintenance are not given sufficient attention.

Quality assurance and quality control need to be given a higher profile and better records of installations and their history need to be readily available. A better appreciation of what pfp systems are intended to do and the importance of timely maintenance, appropriate to the system installed, would contribute to overall safety and reliability.

Contents

8 REFERENCES

1. The Hon. Lord Cullen. The Public Inquiry into the Piper Alpha Disaster. DEn (HMSO) November (1990).

2. International convention for the Safety of Life at Sea, 1974 (SOLAS). International Maritime Organisation, London (1974) and Ammendments (1982).

3. Recommendations for fire test procedures for 'A' and 'B' class divisions. IMO Resolution A.163 (ES IV), 28th November (1968) and Resolution A.215 (VII), 12th October (1971).

4. Code for the construction and equipment of mobile offshore drilling units (MODU Code), IMO (1980).

5. Offshore Installations, Guidance on design and construction. DEn, HMSO (1977).

6. BS 6235 (1982), Code of Practice for Fixed Offshore Structures (withdrawn).

7. Statutory Instrument 289, Offshore installations, The offshore installations (construction and survey) regulations (1974).

8. Exchange of Notes between the Department of Trade, London, and the Direktoratet for Statens Skibstilsyn, Copenhagen, on the application of uniform testing rules for the structural fire protection of ships to comply with the requirements laid down in the International Convention for the Safety of Life at Sea, 1974 (1980).

9. API recommended practice for production facilities on offshore structures. American Petroleum Institute, API RP 2G January (1974). (Currently under review).

10. The DEn/NPD interim hydrocarbon fire resistance test for elements of construction for offshore installations. PEA 68/93/44 (1985).

11. Review of the Department of Energy's offshore fire research programme. F.I. Knight, Marine Technology Support Unit, October (1983) revised by J.A. Bray, October (1984), HMSO (1986).

12. The hydrocarbon fire resistance test for elements of construction for offshore installations. Test Specification - Issue 1. FRS/DEn January (1990).

13. Statutory Instrument 1029, The Offshore Installations (Emergency Pipeline Valve) Regulations (1989).

Contents

14. M. Blake. Fire resistive materials for offshore structures. Seventh International Conference on Offshore Mechanics and Arctic Engineering, Houston, Texas, February 7-12 (1988).

15. PD 6496 (1981), A comparison between the technical requirements of BS 476: Part 8 (1972) and other relevant international standards and documents on fire resistance tests.

16. T.Z. Harmathy and M.A. Sultan. A correlation between the severities of the ASTM E119 and ISO 834 fire exposures. Fire Safety Journal, 13, Nos. 2&3 (1988) 163.

17. A.C. Blake. Structural protection and fire protection claddings. in "Fire protection of offshore platforms - 1". ed R.G. Gower, Applied Science Publishers Ltd.

18. C.I. Smith. Why protect structures and buildings. JOCCA, 5, (1989) 171.

19. D. Levine and D.M. Dancer. Fire protection of railroad tank cars carrying hazardous materials - Analytical calculations and laboratory screening of thermal insulation candidates. Naval Ordnance Laboratory report NOLTR-72-142. 20. W.A. Rains. Fire resistance - how to test for it. Chemical Engineering, 84, (1977) 84.

21. H. Landro. Principles of passive fire protection. SINTEF report STF25 A88037 (1986).

22. D.J. Latham et al. Spray applied fire protection for structural steel. CEC report EUR 10713 EN (1987).

23. BS 8202 Part 1 (1987), Coatings for fire protection of building elements, Part 1. Code of practice for the selection and installation of sprayed mineral coatings.

24. BS 8202 Part 2 (1988), Coatings for fire protection of building elements, Part 2. Code of practice for the assessment and use intumescent coating systems for providing fire resistance.

25. J.V. Dunk (Avco (now Textron) Specialty Materials). The advantages of an epoxy medium as the basis of a durable passive fire protection material. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

26. I. Stewart. The role of magnesium oxychloride in passive fire protection. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

Contents

27. J.R. Petrie and F.I. Knight. Offshore oil: Aims of passive fire protection. Fire, May, No.923, (1982) 670.

28. Fire Protection for Structural Steel in Buildings, ASFPCM (Association of Structural Fire Protection Contractors and Manufacturers (2nd edition) 1988.

29. M.E. Herrera. A comparison of critical properties of magnesium oxysulphate and magnesium oxychloride cements as used in sprayed fire resistive coatings. In Fire Resistive Coatings: The Need for Standards, ASTM STP 826, December (1983) 94.

30. W.R. Parlor (Rockwool limited). The utilisation of mineral wool for offshore fire protection. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

31. H.R. Wesson and J.L. Lott. Effectiveness of fire resistant coatings applied to structural steels exposed to direct flames contact, radiant heat fluxes and mechanical and cryogenic thermal shock. Am. Gas Assoc. Transm. Conf. 33, 9 (1977) T-172.

32. B.H. Van Dyke and S.I. Kawaller. Chemically reactive coatings for passive fire protection in LNG and LPG storage and transportation. Gastech '79 LNG/LPG conference paper (US), 4, 3 (1979) 1.

33. O.H. Larsen (Hempel Holding A/S). Passive fire protection in the hydrocarbon industry. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

34. Control of Substances Hazardous to Health (COSHH) Regulations, Health and Safety Commission (1988).

35. I.D. Howell (BP International limited). An examination of various passive fireproofing materials in the laboratory. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

36. BS 5950 Part 1 (1985), Structural use of steelwork in building, Part 1. Code of practice for design in simple and continuous construction: hot rolled sections.

37. I. Stewart. Tougher materials boost passive fire resistance. Offshore Engineer, October (1986) 46.

38. T. Day. Surface coatings - will time affect their performance. Fire Prevention, 222 (1989) 40.

39. BS 5750 (1987), Quality systems.

Contents

40. A.F. Roberts and K. Moodie. The role of insulating coatings in the fire protection of LPG vessels. JOCCA 5 (1989) 192.

41. G.K. Castle. The nature of various fire environments and the application of modern material approaches for fire protection of exterior structural steel in them. J. Fire and Flammability, 5 (1974) 203.

42. J.F. O'Rourke. The use of intumescent coatings for fire protection of structural steel. In: Loss Prevention, 8, Proceedings of the 8th symposium on loss prevention in the process industries, Philadelphia, Pa. AIChE (1974) 69.

43. C. Lloyd-Lucas (ICI Speciality Chemicals). Improved intumescent fire protection for hazardous environments. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

44. Outline of proposed investigation of structural steel protected for resistance to rapid temperature rise fires, UL 1709, September (1983). American Underwriters Laboratories Inc.

45. BRE News of Fire Research, May (1987) 1.

46. F.M. Stumf. Spray applied fibrous material fire resistive coating. In Fire Resistive Coatings: The Need for Standards, ASTM STP 826, December (1983) 14.

47. E.S. Clark, Jr. Fire retardant coatings. Construction specifier, 28, May (1975) 21.

48. Offshore Installations, Protection against fire and explosion. Discussion document by DEn, PEA 584/411/7, October (1989). 49. G.V.L. Bond. Fire and steel construction: Water cooled hollow columns, Constrado (undated).

50. O.K. Gratzol and M.C. Diliberto. A comparison of fire resistive coatings in ASTM E-119 and proposed ASTM E-5 hydrocarbon pool-fire test environments. In Fire Resistive Coatings: The Need for Standards, ASTM STP 826, December (1983) 68.

51. SINTEF Test Certificate, Task no. 250000.00/88.360, Jet fire test on two steel plates insulated with Chartek. August (1988).

52. J.F. Bennett, T. Cotgreave, L.T. Cowley and L.C. Shirvill. Shell Offshore Flame Impingement Protection Programme: Part 2. Performance of Mandolite 550 coated specimens. Shell Research Limited (1990).

Contents

53. J.F. Bennett, T. Cotgreave, L.T. Cowley and L.C. Shirvill. Shell Offshore Flame Impingement Protection Programme: Part 3. Performance of Chartek Type III coated specimens. Shell Research Limited (1990).

54. H.D. Barnard et al. The development of a superior form of fire protective cladding for quarters at Ekofisk, Norwegian North Sea. J. Petroleum Technology, March 1977) 221.

55. L.T. Cowley and M.J. Pritchard. Large-scale natural gas and LPG jet fires and thermal impact on structures. Gastech 90 conference and exhibition, Amsterdam, 5th December (1990).

56. J.F. Bennett T. Cotgreave, L.T. Cowley and L.C. Shirvill. Shell Offshore Flame Impingement Protection Programme: Part 1. Programme and test description. Shell Research Limited (1990).

57. R. Wighus. SINTEF (1990). Private communication.

58. BS 476 Part 4 (1970), Fire Tests on Building Materials and Structures, Part 4. Non-combustibility test for materials.

59. ASTM E 136-82, Behaviour of materials in a vertical tube furnace at 750°C.

60. H.T. Olstad (Norwegian Petroleum Directorate) NPD's requirements for passive fire protection materials. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

61. A.S. Rehal and E. Mavrommatakis (Det norske Veritas, U.K.). Interpretation and practice of offshore regulations with respect to area separation and other protection measures. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

62. D.V. Whittaker (Lloyd's Register of Shipping). The potential changes to the UK offshore structural fire protection guidance notes. Offshore Passive Fire Protection Seminar. 31st March - 1st April (1987), City Conference Centre, London, EC1.

63. NES 713 Determination of the toxicity index of the products of combustion from small specimens of materials. MOD(PE) Ship Dept., Section D191, Issue 02.

64. Central Electricity Generating Board. E/TSS/EX5/8056. Technical specification and schedules for power station cabling: Cable performance under fire conditions (excluding PVC materials). Issue 2, August (1984).

Contents

65. J.H. Warren and A.A. Corona. This method tests fire protective coatings. Hydrocarbon processing, January (1975) 121.

66. C.E. Anderson, Jr. Rail tank car safety by fire protection. VFDB 6th Int. Fire Protection Seminar, Karlsruhe, II, 21-24 September (1982) 191.

67. Darchem Engineering Limited. Promotional literature.

68. Federal Regulation 49 CFR Parts 173, 179; Docket No. HM-144; Notice No. 76-12, October (1977).

69. Anon. How thermal shields survived a trial by fire. Butane-propane news, May (1982) 48.

70. A.F. Roberts, et al. Fire engulfment trials with insulated LPG tanks. 4th International Conference on Loss Prevention in the Process Industries, I. Chem. E. Symp., Series 82 (1983).

71. W.A. Rains. Evaluation of fire resistant coatings under severe time-temperature exposures. Informal paper presented at 1976 Fall meeting of the API safety and fire protection committee, Fort Lauderdale, 14 September (1976).

72. M.P. Shipp. A Hydrocarbon fire standard - An assessment of existing information. Fire Research Station Report, September (1982).

73. ASTM E-5 Proposal P 191. Proposed test methods for determining effects of large hydrocarbon pool fires on structural members and assemblies.

74. The European Ceramic Fibres Industry Association. Bulletin No. 61, Recommended work practices - Removal of used ceramic fibre linings. September (1985).

75. The European Ceramic Fibres Industry Association. Code of practice. Removal of used ceramic fibre linings - An amplification of ECFIA Bulletin No. 61. September (1985).

76. T.A. Haverstad. Passive fire protection subjected to gas explosion and fire loads. Doctoral thesis, Norges Tekniske Høgskole, Trondheim (1989).

77. DnV Report, Explosion and fire test of fire partition wall protected with Hempel's Contraflam 3810 system. 9th January (1989).

Contents

Table 2.1 Fire Types	
Fire type	Potential duration
Cellulosic fire	hours
Hydrocarbon fires	
Cloud fire	seconds
Fireball / BLEVE	seconds
Pool fire	hours
Running fire	hours
Jet fire	hours
Blowout	days

Table 3.1 PFP, Generic Types	
Generic type	Form
Preformed sections	panel, board, pipe shell
Spray-applied materials	paints, high-build coatings
Blanket/wrap-round systems	random filament or woven sheet, fibre-filled quilt or bag, rope, multi-layer systems, heavy gauge rubber overwrap
Prefabricated sections	fibre blanket or board lined casement, multi-layer metal foil assembly; door, shutter, window assemblies plus frames
Enclosures	box, trunking, shaped blanket
Seals and sealants	preformed, fabricated sleeve, door strip, window opacifier, module seal skirting seal, mastic, formable block, elastomer
Water-fill	hollow steel sections

Contents

Table 3.2 Current Usage of PFP

Location	Type/form
Jacket	Generally none, recent interest in composite systems for legs near to risers, water-fill
Columns	Spray-applied coatings
Deckheads and beams	Spray-applied coatings and blankets
Bulkheads	Spray-applied materials, prefabricated sections
Fire walls	Spray-applied materials, prefabricated sections
Roofing	Generally none externally, some spray-applied coatings
Flare boom	Spray-applied, especially cementitious materials
Drilling derrick	Spray-applied materials
Pipe supports	Spray-applied coatings, preformed sections
Pipes	Generally none, preformed sections
Pressure vessels	Generally none, recent interest in demountable systems that facilitate inspection, effects on blow-down are a concern
Vessel supports	None or spray applied materials
Risers	Generally none, spray-applied coatings, multi-layer and overwrap systems, some concern about application of intumescents to hot risers
Blast walls	None or spray applied materials
ESV (+actuator, etc)	New requirement, enclosures, spray-applied
Cable trays	Generally none, wrap-round systems, enclosures
Penetrations	Seals and sealants, all types
HVAC	Preformed sections, spray-applied materials, blanket and wrap-round systems*.
Fire doors	Prefabricated sections plus seals

* Pfp on trunking used in conjunction with internal intumescent seals and dampers released by fusible links.

Table 4.1 Summary of Fire Ratings and Performance

(times for which performance aspect must be sustained are expressed in minutes)

Classification	Stability & Integrity	Insulation performance
H120	120	120
H60	120	60
H0	120	0
A60	60	60
A30	60	30
A15	60	15
A0	60	0
B15	30	15
B0	30	0

"C" rated partitions need meet none of these criteria but must be essentially non-combustible.

Contents

Table 5.1 Accelerated Weathering Tests

Test	BS 8202 Part 2 (draft)	Underwriters Laboratories
Heat exposure	6 months @ 60°C	270 days @ 70°C
Washing	20 cycles with soap water & air drying	
Freeze-thaw	10 cycles @-20°C for 24 h, +20°C for 24 h	12 cycles, wet for 72 h, -40°C for 24 h dry @ 60°C for 72 h
Sulphur dioxide	20 cycles @ 0.2 l per 300 l (BS 3900 Part F8)	30 days @ 35°C in moist 1% SO_2 + 1% CO_2
Humidity	2000 hours cycling 42-48°C @ 100% RH (BS 3900 Part F2)	180 days @ 35°C 97-100% RH
Weatherometer	2000 hours @ 20°C + carbon arc (BS3900 Part F3)	
Salt spray	2000 hours @ 20°C artificial sea water (BS 3900 Part F4)	90 days @ 35°C 5% salt solution (ASTM B117-3 1979)
Natural exposure	2 years minimum a) industrial environment b) marine environment	
Acid environment		5 days in 2% HCl @ unspecified temp.
Solvent exposure		5 cycles, solvent spray until excess off, dry for 6 h, respray, dry for 18 h

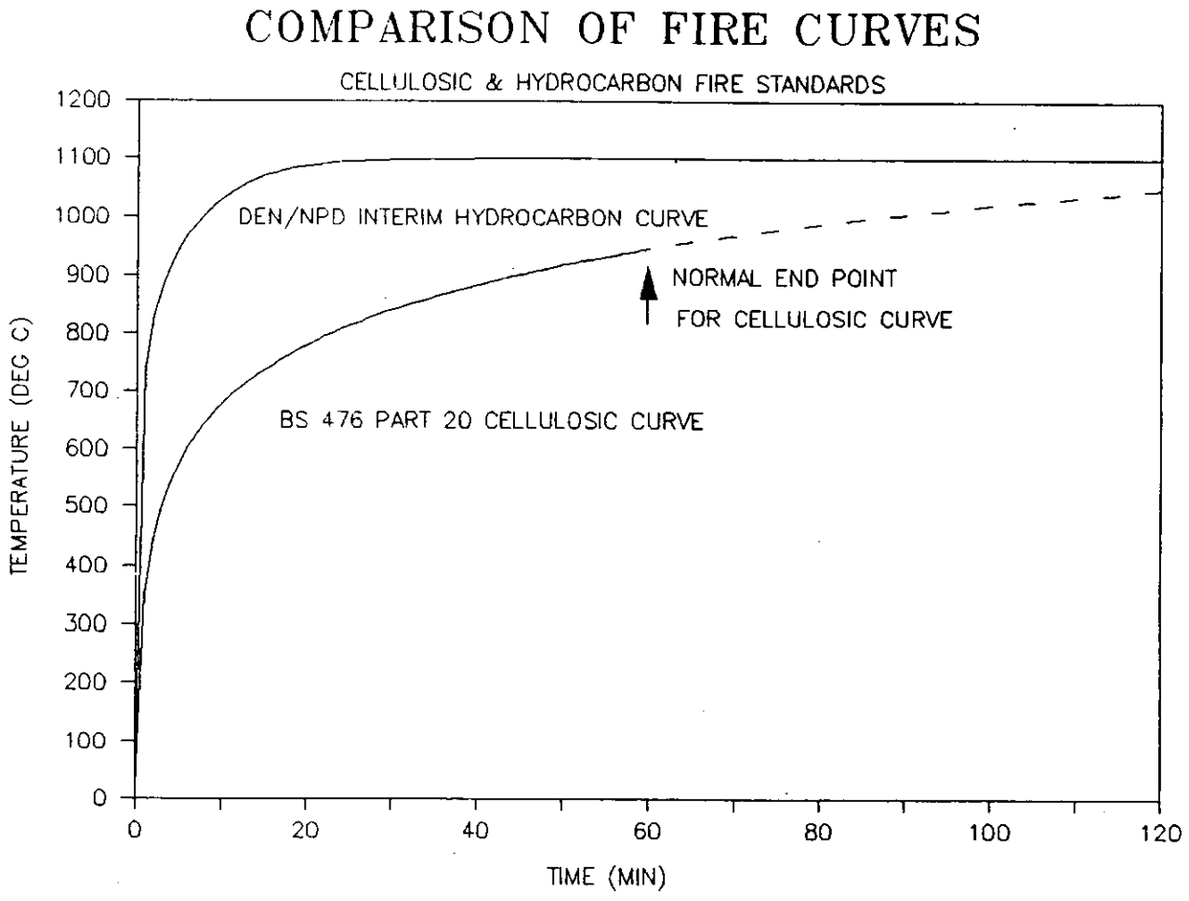


Figure 4.1

Contents

APPENDIX A - THE FR3 WORK PACKAGE

BLAST AND FIRE ENGINEERING FOR TOPSIDE STRUCTURES WORK PACKAGES (WP)

WP No: FR3
WP TITLE: Passive fire protection - performance requirements and test methods

---

WP START DATE: Month 1 **DURATION:** 9 Months
WP END DATE: Month 6 & Month 9

OBJECTIVES:

To assess the performance requirements for offshore passive fire protection systems and the adequacy of current methods for the prediction or measurement of the performance.

To identify gaps in knowledge.

DESCRIPTION OF WORK:

Passive fire protection might be applied to primary support structures, secondary structures and to selected process plant. These applications have differing requirements as do those of directly protecting personnel and accomodation units.

Performance requirements in most protection applications include:

- Limitation of system temperatures or heat flux for a defined time
- Abrasion and erosion resistance
- Production of fumes and smoke
- Explosion and overpressure deformation survivability
- Impact response
- Response to deluge and thermal shock
- Durability to weathering and mechanical damage
- Assessibility of fire performance

The performance requirements of offshore passive fire protection systems will be evaluated against fire scenarios for offshore structures. The study will examine the applicability of current methods for the prediction and evaluation of the fire response of protection systems, and identify further knowledge necessary for the specification and evaluation of passive fire protection systems.

INPUT TO ACTIVITY:

Other fire loading and response studies. Published research and information made available by research organisations, co-operating organisations, participants and fire protection system manufacturers.

DELIVERABLES

A report assessing the performance requirements for offshore passive fire protection systems, examining current methods for prediction and for measurement of performance. Requirements for future work.

Contents

HSE
BOOKS

MAIL ORDER
HSE priced and free
publications are
available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 6FS
Tel: 01787 881165
Fax: 01787 313995

RETAIL
HSE priced publications
are available from
good booksellers.

HEALTH AND SAFETY ENQUIRIES
HSE InfoLine
Tel: 0541 545500
or write to:
HSE Information Centre
Broad Lane
Sheffield S3 7HQ

1 873 0011 Fax 071 873 8200 (counter service only)
21 643 3740 Fax 021 643 6510
S1 2BQ 0272 264306 Fax 0272 294515
S 061 834 7201 Fax 061 833 0634
238451 Fax 0232 235401
1 228 4181 Fax 031 229 2734

ISBN 0-11-882095-8
9 780118 820950

£10.00 net

Contents